Populations of Herring (*Clupea harengus* L.) in Newfoundland Waters[1,2]

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ABSTRACT

Four separate and distinct populations of herring have been identified in Newfoundland waters. They are located during spawning seasons in Bay of Islands, Fortune Bay, Placentia Bay and Notre Dame Bay. They are distinguished by differences in growth, "diameter" of the scales at the end of the first year, and average vertebral counts, also by the length, age, and year-class composition of the spawning aggregations. The herring that are caught off the Labrador coast may be an older and more migratory part of the population that spawns in Notre Dame Bay. The number of vertebrae tends to decrease from south to north in the Newfoundland area, which is the reverse of what is found elsewhere, but temperature *at spawning* may increase from south to north for these populations. The present fishery is chiefly for large (32.4 to 36.4 cm.) and old (7.4 to 11.9 yr.) herring and it is evident that catches could be increased considerably.

INTRODUCTION

DURING the past century the Newfoundland herring fishery has been located chiefly in Bay of Islands on the west coast. Previous to and during the World War of 1914–18 herring fisheries were carried on in Fortune Bay and Placentia Bay on the south coast, and in Notre Dame Bay on the northeast coast. These fisheries were not as extensive as the Bay of Islands fishery and they declined during the early 1920's, chiefly because of poor market conditions. The markets for pickled herring were small and competition from the Pacific coast and North Sea fisheries was keen. The result was that very little fishing was done anywhere in Newfoundland except in Bay of Islands and there the catch was reduced considerably.

The possibility of expanding the herring fishery was explored in the early 1930's. The Newfoundland Fisheries Board investigated existing food markets and attempted to establish new ones. Financial support was given to an experiment designed to promote a herring meal and oil industry. The overall result was an increase in fishing effort and within a few years (1939–1946) the catch was increased more than five times.

The increase in fishing intensity caused some concern and a survey of the Newfoundland herring resources was suggested by the Newfoundland Fisheries Board and carried out by the author. This paper is a report of the investigation

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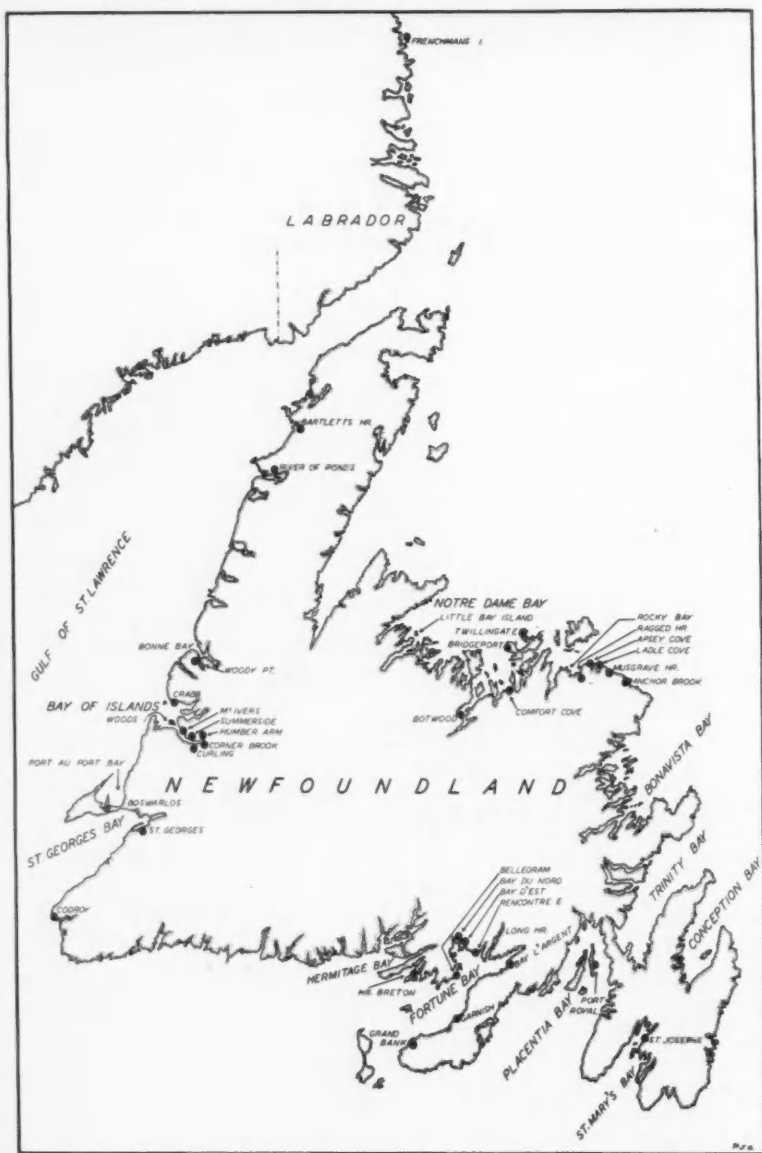
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FIG. 1.—Map of Newfoundland and Labrador showing areas and localities metnioned.

TABLE I.—List of samples, localities and methods of capture.

Season	Area	Locality	No. of samples	No. of fish	Method of capture
1943	Labrador	Frenchmans I.	3	300	Traps
1942	Notre Dame Bay	Little Bay I.	1	110	Gill nets
1943	Notre Dame Bay	Comfort Cove	4	386	Gill nets
1942–43	Bay of Islands	Curling	24	2574	Gill nets
		Woods I.	10	1100	Traps
1943–44	Bay of Islands	Summerside	12	1290	Gill nets
		McIvers	3	327	Seines
		Woods I.	7	769	Seines
1943	Placentia Bay	Port Royal	1	109	Gill nets
1943	Fortune Bay	Belleoram	10	1099	Gill nets
1944	Fortune Bay	Bay L'Argent	14	1540	Gill nets
		Rencontre East	3	328	Seines

and gives the results of a study of length, age, and year-class composition of samples of herring taken from commercial catches in five separate areas. Growth, development of the gonads, mean vertebral counts and the "diameter" of scales during the first year were also studied. The investigation was designed to test the homogeneity of the Newfoundland herring stocks and to determine whether there was any danger of overfishing.

MATERIALS AND METHODS

Figure 1 is a map of Newfoundland and southern Labrador showing the general areas from which samples of herring were obtained. The localities mentioned in this report are included. Table I gives a list of samples from the various areas according to season and method of capture. In general, each sample consisted of 110 herring. For the most part the herring were examined fresh but there were some preserved samples.

The sample from Placentia Bay and the four samples from Notre Dame Bay taken in 1943 were preserved in a five per cent aqueous solution of phenol for two to three weeks. Before examination the fish were soaked in water for twenty-four hours. Length measurements for herring in preserved samples were corrected for shrinkage using the formula $y = 1.033x - 0.214$ where x is the observed length and y the corrected length. This formula was calculated from unpublished data by Mr. R. V. Boughton for standard lengths of 16 to 22 cm. During the initial stages of the investigation standard lengths were used but the majority of length measurements were total lengths. Except where otherwise stated total lengths are used in this report.

Standard length is described as the length from the tip of the lower jaw with the mouth closed to the end of the silvery area on the caudal peduncle (scales were removed from the area before measuring). Total length is the length to the end of the longer lobe of the caudal fin extended straight back in line with the body. The conversion from standard length (x) to total length (y) was made using the formula $y = 1.143x + 1.071$ (Tibbo, 1956).

For age determinations and scale "diameter" measurements scales were taken from the middle of the lateral surface of the body within the radius of the tip

of the pectoral fin. The herring were cooked for 10 to 15 minutes and the flesh removed so that the number of vertebrae could be counted. Vertebral numbers do not include either the basi-occipital bone or the urostyle. On the basis of appearance and the size of the gonads in relation to the part of the body cavity that they filled, the state of gonad development was divided into six groups as follows:

Stage I — Immature (gonads small, flattened and pinkish in appearance).
Stage II — Filling to ¼ full.
Stage III — ¼ to ½ full.
Stage IV — ½ to ¾ full.
Stage V — ¾ full to ripe and running.
Stage VI — Spent (ovaries with residual eggs; testes loose and bloodshot).

AVERAGE LENGTHS AND LENGTH-FREQUENCY DISTRIBUTIONS

Table II gives the average lengths and ages of herring from the various areas. The slightly larger average lengths for herring from Bay of Islands and

TABLE II.—Mean lengths and ages of herring from the various areas. (Number of fish in parentheses.)

Season	Area	Average length	Average age
		cm.	*years*
1943	Labrador	36.41 (300)	11.88 (212)
1942	Notre Dame Bay	32.41 (110)	7.37 (110)
1943	Notre Dame Bay	32.59 (386)	7.99 (378)
1942–43	Bay of Islands	34.85 (3674)	10.87 (3588)
1943–44	Bay of Islands	35.22 (2386)	9.66 (1085)
1943	Placentia Bay	33.12 (109)	8.18 (109)
1943	Fortune Bay	34.76 (1099)	9.16 (478)
1944	Fortune Bay	34.98 (1868)	9.66 (531)

Fortune Bay from one season to the next may be accounted for by the fact that a higher proportion of the samples during the second season was obtained from seines and traps. Seines and traps are less selective than gill nets and a comparison of catches from the same area and on the same day showed that the average length of herring from gill nets of 2¾-inch stretched mesh (the most frequently used mesh size) was slightly less (0.4 cm.) than the average length of herring from seines and traps. Table II shows, however, that irrespective of the method of capture, the largest herring are found off the coast of Labrador and the smallest herring in Notre Dame Bay. The average lengths of herring from Fortune Bay and Bay of Islands are intermediate with no significant differences between them.

YEAR-CLASS COMPOSITION

The importance of year-class composition in the study of herring populations has been demonstrated by many workers. Hodgson (1934) has shown the effect of variations in the relative success of year-classes on the commercial fishery. Hjort and Lea (1911), Lea (1911), Hodgson (1925) and Ford (1933) have all

shown how a very successful year-class will predominate in a fishery for several years.

Age determinations were made to establish the average age and the percentage frequency of year-classes in the commercial catches from the various areas and also to discover whether populations could be recognized on the basis of year-class composition. Preliminary studies indicated that the scales described as "side scales" by Huntsman (1918) were most satisfactory for age determinations and as far as was possible only these scales were used. "Side scales" are the scales from the middle of the lateral surface of the body within the radius of the tip of the pectoral fin. It was found that the exact age of individual herring is often doubtful. A check was made on the age determinations by re-reading 1,000 scales from the Bay of Islands samples. A comparison of these results with the original readings showed that for fish less than 9 years old 92 per cent of the readings were identical but for fish more than 9 years old the readings were identical in only 48 per cent of the cases. The difference was usually one year and in only three cases was it more than two years. This difficulty in age determinations is attributed to the fact that the winter rings for herring more than 7 or 8 years old are not sharply defined and tend to run together at the periphery of the scale.

For the Newfoundland area the innermost annuli were distinct in all localities. Scales from the Notre Dame Bay samples presented the least difficulty while Bay of Islands samples were sometimes confusing. Lea (1919) states— "On the whole it may be said that the Newfoundland material from the Gulf of St. Lawrence is to be regarded as well suited for the purpose of age determinations, whereas some part of that from the open coast presents many difficulties". Our experience has been that the material from Fortune Bay and Notre Dame Bay on the open coast is much less difficult than the material from Bay of Islands in the Gulf of St. Lawrence. However, regardless of the accuracy of individual age determinations, there are significant differences in the appearance of scales from herring in different areas, which is in itself enough to indicate distinctness of stocks.

The primary scale reading made was of the *year-class* to which the fish belonged, considered on the basis that it was hatched in the spring and that growth during the year of birth was sufficient to be recorded on the scales. In addition the "age" was recorded as the number of summer zones on the scale, *including incomplete ones*. Fish captured in May, when just completing a year of life, were assigned the age of the year being completed. Fish taken in August or later all had new summer growth on their scales and were assigned an "age" equal to the number of summer growth areas, including the current one. During June and July it usually happened that some fish of a given year-class had new summer growth whereas others did not. In such event, when a majority of the fish in the whole sample had new summer growth, the current year was included in the "age" for *all* fish. Figure 2 indicates which ages were assigned in any given sample.
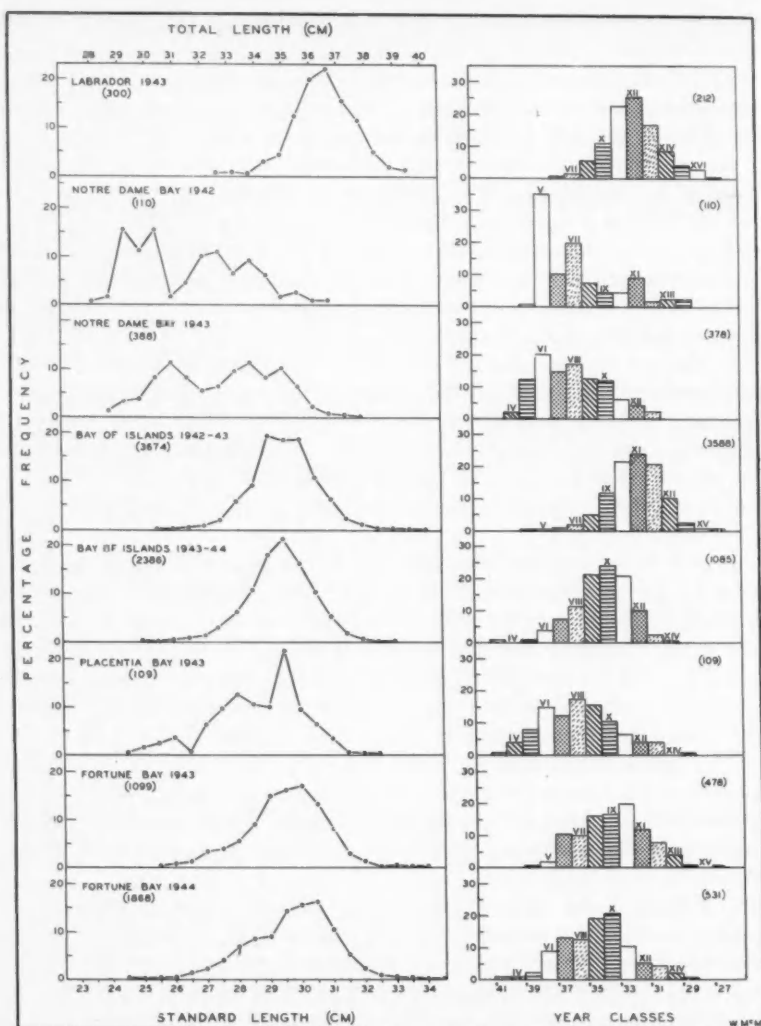
Fig. 2.—Length and age distribution of herring from the various areas.

In the *Notre Dame Bay* area, the 1936 and 1938 year-classes were particularly abundant and their relative importance was evident in both the 1942 and the 1943 samples (Fig. 2). The 1932 year-class was relatively abundant in the 1942 samples but its importance was lost in 1943. The 1942 sample was small and the importance of dominant year-classes may be over-emphasized.

In the samples from *Labrador* the distribution of year-classes was more symmetrical than for Notre Dame Bay samples and the difference in age com-

position is apparent. Approximately 80 per cent of the herring from Notre Dame Bay were less than 10 years old, whereas 90 per cent of the herring in the Labrador samples were 10 or more years old. The average age of the 1943 samples differed by nearly four years (Table II).

There was a distinct difference in the year-class composition of the samples from *Bay of Islands* for the two seasons (Fig. 2). In both cases the distribution about the mean is symmetrical but the average age decreased from 10.87 years in 1942–43 to 9.66 years in 1943–44 (Table II). Other aspects of the investigation do not suggest more than one population of herring in the Bay of Islands, and since there is apparently no *wide* variation in the relative strength of year-classes, the decrease in average age may have been due either to (a) variations in the distribution of herring of various ages or (b) a migration of older fish away from the area.

In the samples of herring from *Fortune Bay* the relative importance of four consecutive year-classes (1934 to 1937) was approximately the same for both seasons (Fig. 2), and the average ages are similar (Table II). The sample from *Placentia Bay* was different in that 8-year-old herring (1936 year-class) predominated, whereas in the Fortune Bay samples 10-year-old herring (1933 year-class in 1943 and 1934 year-class in 1944) were most abundant. The relatively large numbers of 1938 year-class herring in the Notre Dame Bay samples might account for the slight increase in the average age from 1942 to 1943 (Table II).

The value of year-class abundance for distinguishing populations is questionable. The widest variations were found between Notre Dame Bay and Labrador herring. Fortune Bay and Bay of Islands samples were very similar, especially for the 1943–44 season, and it is doubtful that they could be distinguished from each other on the basis of year-class abundance alone.

GROWTH

Tester (1937) has shown that for the Pacific herring there is a tendency towards sexual difference in growth in certain localities. He found that in the Saltspring Island and Barkley Sound populations the females were slightly larger than the males of the same year-class and that this difference persisted over several seasons. In samples of the size examined in Newfoundland there are no demonstrable differences between the average lengths of males and females of the same age and they were combined for consideration of growth. Jean (1945) was also unable to demonstrate differences between the average lengths of males and females of the same age for herring from Rivière Madeleine in the Gulf of St. Lawrence.

Figure 3 shows the average lengths of herring of various ages from the five areas from which samples were obtained. There were considerable differences in growth up to the ninth year but for greater ages the curves are similar. As mentioned previously the ages of older herring are difficult to determine accurately. The number of specimens in the older age groups is comparatively small and the growth curves are certain to be affected by gear selectivity. These factors contribute to errors in the growth curves.
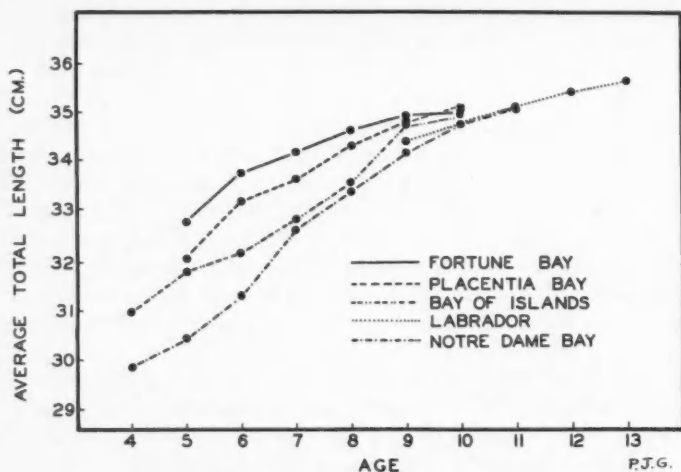
Fig. 3.—Rates of growth of herring from the various areas.

There were very few fish in any of the samples that were less than 4 years old and hence the growth curves are incomplete but they show the relationship that exists between lengths and ages of the spawning stock in the various areas.

Although the curve for Labrador samples is scarcely comparable to the others, since it contains only averages for herring that are more than 9 years old, it shows a similarity between herring from Labrador and from Notre Dame Bay.

The growth curves (Fig. 3), show that growth up to the ninth or tenth year is greatest in the Fortune Bay area, slightly less in Placentia Bay, still less in Bay of Islands and least in Notre Dame Bay and Labrador. This order in decreasing average size at the same age from south to north might be expected because of differences in the duration of the growing seasons. However, it does not explain the difference between Fortune Bay and Placentia Bay that are in approximately the same latitude.

"DIAMETER" OF SCALES AT THE END OF THE FIRST YEAR

It has been assumed throughout that there is sufficient development of the scales of herring spawned in the spring and early summer to permit the recording of the first winter. This assumption is based on the examination of young herring captured in the Notre Dame Bay area during the latter part of September, 1940. While there was no evidence of a winter check on the scales, the development appeared to be sufficient to record any retardation of growth. The average length of the herring was approximately 5 cm. However, the specimens were preserved in formalin and no correction was made for shrinkage. It is almost certain that these herring were spawned in 1940.

Huntsman (1919) has shown that spring-spawned herring in the Bay of Fundy will grow to a length of approximately 9 cm. in their first complete year. Hodgson (1934) has indicated that, for herring in the North Sea, the develop-

ment of summer- and fall-spawned herring is not sufficient for the first winter to be recorded on the scales but that this condition does not hold for spring-spawned herring. As far as can be ascertained the only spawning that has been observed on the Newfoundland coast has been in the spring or early summer and hence it is considered most likely that in general, the first winter will be recorded on the scales of herring in the Newfoundland area.

The possibility of a difference in scale "diameters" for the first year was considered as a method for distinguishing populations. It is known that the time of spawning varies in different localities and it was thought likely that the time element would be reflected in the amount of growth of the scales.

Hodgson (1934) discussed the significance of scale growth in the first year and demonstrated the degree of variation found in different localities. He pointed out, however, that differences or similarities in scale growth were not necessarily in agreement with differences in vertebral counts.

Measurements were made of the "diameters" of scales at the end of the first year from four areas using a Promar projector that had been modified in a manner similar to that described by Tester (1941). The results, that are based on averages of at least ten scale measurements, are given in Figure 4. The
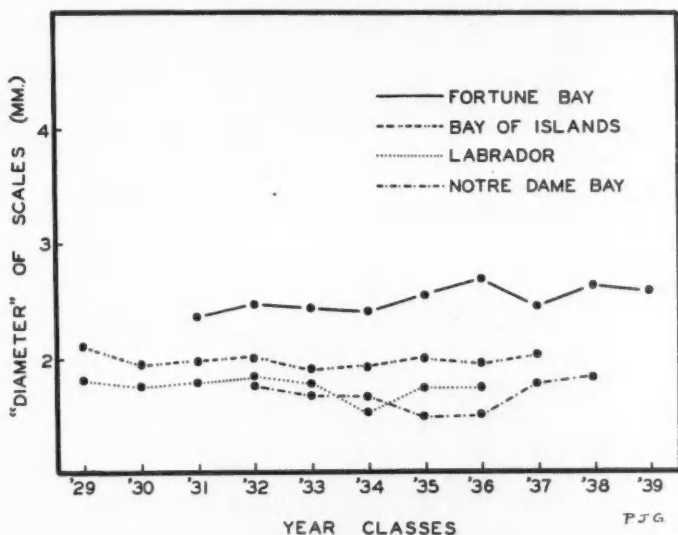

FIG. 4.–Scale diameters at the end of the first year for four areas.

measurement that was made is indicated in Figures 5a, 5b and 5c which also shows typical scales for three areas.

The first-year scale "diameter" is greatest in the Fortune Bay area (2.4 to 2.7 mm.), intermediate in the Bay of Islands area (1.9 to 2.1 mm.), and least in Notre Dame Bay and Labrador (1.5 to 1.7 mm.).
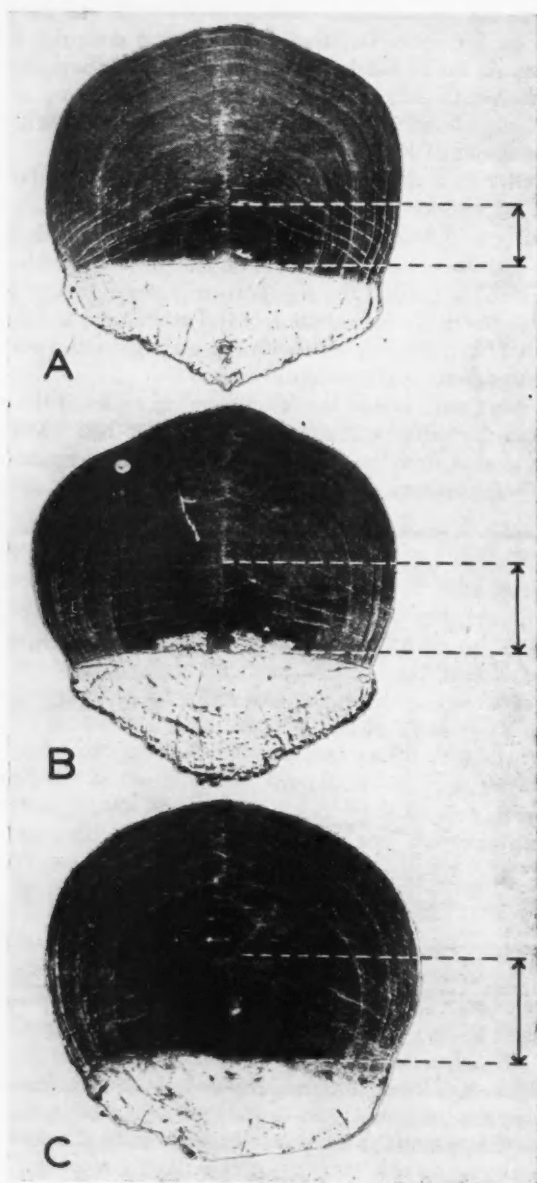
FIG. 5.—Photographs of typical herring scales. A. Notre Dame Bay. B. Bay of Islands. C. Fortune Bay.

Except for Notre Dame Bay and Labrador, there is no overlapping of the curves. Hence it is possible to distinguish the different *populations* by measuring the "diameter" of the scales at the end of the first year.

In these areas the differences in the scale "diameters" were very apparent and corresponded with differences in vertebral counts. However vertebral counts are determined by the conditions under which spawning and early development takes place and this may have no relationship to scale growth. As Hodgson (1934) points out, similar amounts of growth may be observed among populations that, on the basis of vertebral counts, are separate and distinct.

It is sometimes impossible to distinguish populations on the basis of vertebral counts and in these cases scale diameters may provide useful information that is not available otherwise.

SPAWNING DATES AND LOCALITIES

During the 1943 and the 1944 seasons an attempt was made to obtain information on the spawning habits of herring around the coasts of Newfoundland. During the early stages of this investigation it was observed that the development of the gonads was well advanced in herring that migrated into the bays and inlets in the fall and winter months. This was particularly true in the case of the males, most of which had reached Stage V (¾ full to ripe and running) when the fishery started in November.

The development of the ovary appears to be somewhat slower although by the middle of December approximately 70 per cent of the females had also reached Stage V. Further development of the gonads is slowed down or stopped altogether until a week or ten days before spawning in the late spring.

Table III gives the percentage of herring in Stage V of sexual development

TABLE III.—Percentages of herring in Stage V (i.e. ¾ full to ripe and running) of sexual maturity. Samples from Humber Arm, Bay of Islands, 1941.

Period	No. of males	Per cent in 5th stage	No. of females	Per cent in 5th stage
Nov. 10–16	148	94.5	145	20.0
Nov. 17–23	64	93.8	86	26.9
Nov. 24–30	188	95.2	156	40.5
Dec. 1–7	157	99.4	158	68.4

in samples from Humber Arm, Bay of Islands, for four weeks; November 10 to December 7, 1941. Whereas on the week beginning November 10, 94.5 per cent of the males were in Stage V, only 20.0 per cent of the females had reached this stage. By December 7, however, practically all (99.4 per cent) of the males and 68.4 per cent of the females were in Stage V.

During the spawning survey it was observed that, for the most part, herring spawn from close inshore to a depth of five or six fathoms. Spawning in deeper water was reported occasionally, chiefly from outer sections of the coast where the water is deep close to the shore and where onshore winds cause rough

surface water conditions. Herring usually spawn on gravel or rocky bottom where there is an abundance of seaweed although some spawning was observed on sandy shores and on bare rock.

The main spawning areas are located at the heads of the various bays and deep inlets around the Island.

The following statements were extracted from "Herring Spawning" reports submitted by Fishery Officers for the year 1943.

Mr. H. M. Piercey, Fishery Officer for Notre Dame Bay, stated—"On June 20, I passed through water almost as white as milk for a distance of twenty miles. The spawning ground extended from Rocky Bay Point to Anchor Brook on that part of the coast which includes Apsey Cove, Ladle Cove, White Point and Musgrave Harbour. The spawning extended from close inshore to nearly a mile offshore in some places. Rowing ashore the paddles of the boat would turn up herring. This school of herring stayed for four days and then disappeared. They spawned in a depth of water from one foot to four fathoms."

Inspector L. Hamilton reported for the Hermitage Bay area as follows—"Herring, during the spawning season, go very close to the shore and spawn in very shallow water. In Bay d'Est and Bay du Nord herring have gone in on high water and spawned. When the water fell the bottom was covered with spawn."

Mr. Wm. Humphries, Fishery Officer for Fortune Bay wrote—"The distance from shore and depth of water where spawning occurs varies. For example, sometimes herring will spawn in very shallow water, just enough to cover the fish, while on other occasions they are known to deposit their spawn in water up to a depth of ten fathoms but not more than eighty fathoms from the land."

On the south coast the spawning season starts during the second week in May and is usually over by the first week in June (Table IV). On the west coast spawning does not commence before the last week in May and continues until the middle of June, except in the most northerly areas where spawning is not completed until June 20. On the east coast spawning starts during the second week in June and extends to June 20. As far as can be ascertained spawning has not been observed on the coast of Labrador.

The variation in the time of spawning is probably due to differences in water temperature. The absence of ice in Fortune Bay suggests that surface water temperatures, during the early spring are higher in this area than they are in Bay of Islands and Notre Dame Bay. The fact that the disappearance of ice is about three weeks later in Notre Dame Bay than it is in Bay of Islands indicates that the process of surface water warming is later in Notre Dame Bay.

Mean air temperatures during spawning periods on the south, west and east coasts of Newfoundland for three consecutive years 1936, 1937, and 1938 are given in Table V. The figures were calculated from the daily maximum and minimum temperatures given in the monthly Reports of the Meteorological Service of Canada. The points of reference chosen, viz. Grand Bank, Corner Brook, and Botwood are the places nearest to the spawning grounds for which such data are available.

TABLE IV.—Spawning localities and dates as observed by Fishery Officers for 1943.

Area	Earliest and latest spawning dates
East Coast	
Rocky Bay, Notre Dame Bay	June 9–June 20
Apsey Cove, Notre Dame Bay	June 9–June 20
Twillingate, Notre Dame Bay	June 5–June 10
Bridgeport, Notre Dame Bay	June 8–June 10
Ragged Hbr., Notre Dame Bay	June 10–June 14
West Coast	
Codroy	June 8–June 12
St. Georges, Bay St. George	June 8–June 12
Boswarlos, Port au Port Bay	June 11–June 17
Woods I., Bay of Islands	June 2–June 16
Crabbs Brook, Bay of Islands	June 2–June 16
Woody Point, Bonne Bay	May 24–June 7
River of Ponds	June 16–June 20
Bartletts Hbr.	June 16–June 20
South Coast	
Bay d'Est, Hermitage Bay	May 12–June 1
Bay du Nord, Hermitage Bay	May 12–June 1
Harbour Breton, Fortune Bay	May 12–May 23
Long Hbr., Fortune Bay	May 12–May 23
Bay L'Argent, Fortune Bay	May 20–June 5
Garnish, Fortune Bay	May 15–May 25
St. Josephs, St. Mary's Bay	May 20–June 3

Although the relationship between air and water temperatures in these localities has not been established, it is considered likely, that, in general, there will be variations in water temperatures similar to the variations that have been observed in air temperatures.

For the areas under consideration, the mean air temperatures during spawning tend to increase with increasing latitude (Table V). This is true in all cases for the three seasons that have been selected. Similar conditions may exist in water temperatures. Since spawning is progressively later going from south to north and since herring eggs are deposited in shallow water it has been concluded that the development of the eggs will take place in higher temperatures on the east coast than on the south coast and that the west coast will be intermediate.

Studies on the development of the vertebral column have indicated that the number of vertebrae has already been established at the time of hatching (Ramanujam, 1929; Gwyn, 1940). Hence the effect of temperature on the num-

TABLE V.—Mean air temperatures during spawning periods. Calculated from daily maximum and minimum temperatures. Source: Monthly Reports of the Meteorological Service of Canada for 1937, 1938, and 1939. Toronto.

Area	Locality	Latitude	Period	Mean air temperatures		
				1936	1937	1938
Notre Dame Bay	Botwood	49° 09′ N.	June 5–June 20	59.1	60.1	57.2
Bay of Islands	Corner Brook	48° 56′ N.	May 24–June 16	55.5	56.9	54.7
Fortune Bay	Grand Bank	47° 04′ N.	May 12–June 3	49.9	45.2	44.9

ber of segments in the vertebral column will be exercised only during the short egg-stage.

Tester (1937) has shown that mean vertebral counts vary inversely with air temperatures. It is therefore to be expected that mean vertebral counts will be relatively high on the south coast, intermediate on the west coast and low on the east coast.

VERTEBRAL COUNTS

An important aspect of this investigation was to determine whether the stocks of herring found in Newfoundland waters belong to a single, homogeneous population or whether there are a number of separate and distinct localized groups that intermingle to a limited extent, if at all. For similar investigations elsewhere mean total vertabral counts have been used and have been correlated with water temperatures during the period of development (Tester, 1938; Tåning, 1944). More positive evidence of the existence of local populations is supplied by the results of the tagging of Pacific herring which indicate that the amount of intermingling, at least for adult fish, is small (Hart and Tester, 1938).

The areas in Newfoundland from which samples of herring were obtained are quite widely separated (Fig. 1). Except for Fortune Bay and Placentia Bay there is a distance of approximately 300 miles of coastline between each of the areas. It can be expected, therefore, that the temperature conditions under which herring spawn and develop in the various areas are different and that a difference in mean vertebral counts will result. Such differences would persist throughout the life of the herring and would be detectable if the stocks remained separate throughout their existence.

Vertebral counts were made of all herring in the samples and the means were compared within and between areas. Differences between means for samples from the same area were tested for statistical significance using the t-test (Fisher, 1936). The procedure was to compare individual sample means with the overall mean for the area. Since all samples were large, the t-value for $P_{0.05}$ is always close to 1.96 and for $P_{0.01}$ is close to 2.58. The calculated t-values were less than 1.96 for all samples from Labrador and Notre Dame Bay. They were less than 2.58 in 51 out of 56 cases and less than 1.96 in 49 out of 56 cases in the Bay of Islands samples. For Fortune Bay the t-values were less than 2.58 for 25 samples and less than 1.96 for 24 out of the 27 samples. It is probable, therefore, that only one population of herring was sampled in each area and that the observed differences in means within an area are normal variations due to selective sampling or to year-class differences.

The overall frequencies and means for the various areas are given by seasons in Table VI and are compared by analysis of variance (Snedecor, 1946). The calculated F-value is highly significant and it is almost certain that the samples were not drawn from a single population.

The next step was to make individual area comparisons. Since the degrees of freedom are one for the between variation and because the samples are large, the F-value for $P_{0.05}$ is always close to 3.84 and for $P_{0.01}$ is close to 6.64. The

TABLE VI. — Vertebral frequencies and mean vertebral counts from the various areas.

| Area | Season | Number of vertebrae | | | | | | | | Total | Mean | s.s. |
		52	53	54	55	56	57	58	59			
Labrador	1943	1	0	15	138	121	15	..	..	290	55.459	144.003
Notre Dame Bay	1943	..	1	16	182	139	13	0	1	352	55.429	162.224
Bay of Islands	1942–43	2	4	158	1446	1429	285	18	1	3343	55.564	1876.115
Bay of Islands	1943–44	1	1	90	1003	953	208	17	1	2274	55.584	1280.289
Placentia Bay	1943	..	..	4	42	49	11	1	1	108	55.685	71.296
Fortune Bay	1943	..	2	28	367	523	146	7	..	1073	55.749	603.562
Fortune Bay	1944	1	2	26	531	865	235	15	2	1677	55.808	920.173
												5057.460
Total		5	10	337	3709	4079	913	58	6	9117		5168.460

Source	df.	s.s.	m.s.	F	P = 0.05 P = 0.01
Between	6	110.798	18.466	33.27	2.01
Within	9110	5057.662	0.555		2.64
Total	9116	5168.460			

difference between means for the two seasons in Bay of Islands (F $=$ 1.02) is not significant. The difference between means for Fortune Bay (F $=$ 4.07) is not significant at the 0.01 point. The comparison between Labrador and Notre Dame Bay means gave an F-value of 0.29, also not significant. Between combined samples from these two areas and Bay of Islands, Placentia Bay and Fortune Bay, the F-values were 17.53, 10.79 and 113.00 respectively—in all cases highly significant. The difference between means for Bay of Islands and Fortune Bay was also highly significant (F $=$ 149.43). Between these two areas and Placentia Bay the F-values were 2.40 and 1.86, respectively and are only significant at about the 10 per cent point. There was only one sample from Placentia Bay and the results are less reliable than from other areas where a large number of samples were examined.

DISCUSSION AND CONCLUSIONS

The characteristics of the herring populations in the various areas are summarized in Table VII. The differences between all areas excepting Labrador and Notre Dame Bay are apparent.

It has been concluded, therefore, that in Newfoundland waters there are separate and distinct populations of herring that intermingle to a limited extent, if at all. Except in the case of Notre Dame Bay and Labrador, these populations may be distinguished on the basis of differences in average length and length–

Table VII. — Summary of population characteristics for the various areas.

	Labrador	Notre Dame Bay	Bay of Islands	Placentia Bay	Fortune Bay
Av. length (cm.)	36.4	32.5	35.1	33.1	34.9
Av. age (years)	11.9	7.8	10.6	8.2	9.4
Dominant year-classes	'32	'32, '36, '38	'32, '34	'36, '38	'33, '34, '37
Growth (cm.)					
(Av. length end of 5th yr.)	30.5[a]	30.5	31.4	32.2	32.8
Scale diameter, 1st yr. (mm.)	1.5–1.7	1.5–1.7	1.9–2.1	2.2	2.4–2.7
Spawning (1943)	...	June 9–14	May 24–June 20	May 20–June 3	May 12–June 5
Av. vertebral count	55.46	55.43	55.57	55.69	55.79
Approximate latitude	53°N.	50°N.	49°N.	47.6°N.	47.5°N.

[a]Calculated from scale measurements

frequency distributions, average age and year-class composition, rate of growth in length, "diameter" of the scales at the end of the first year and mean vertebral counts. Notre Dame Bay and Labrador herring differ only in length and age composition. No spawning has been observed on the Labrador coast but similarities in mean vertebral counts, growth rates and scale diameters suggest that conditions of spawning and early development are very similar for both the Labrador and Notre Dame Bay herring. It is possible that the herring found off the coast of Labrador represent an older and more migratory part of the Notre Dame Bay population.

Mean vertebral counts tend to decrease with increasing latitude. This relationship is the reverse of that found elsewhere. Spawning periods are progressively later going from south to north and mean air temperatures during the spawning periods are higher in the more northerly areas. Templeman (1948) showed similar variations in the mean vertebral counts of caplin. Surface water temperatures are influenced to some extent by air temperatures. These herring spawn in relatively shallow water, sometimes within the intertidal zone where, at low tide, they will be exposed to the air. Hence, although Notre Dame Bay is approximately 150 miles farther north than Fortune Bay, development takes place in higher temperatures and this is reflected in a lower average number of vertebrae.

The landings of herring that are made in the Newfoundland area consist, chiefly, of large, old fish that have spawned several times. The larger sizes of herring are most valuable for present markets and catches are made with selective gear that is most efficient for these sizes. There are, apparently, sufficient quantities of large herring to maintain the fishery at its present level. The smaller herring are not taken in quantity, at present, and could form the basis of an extensive fishery. In relation to the optimum the present fisheries are probably very small.

SUMMARY

1. Samples of herring were obtained from commercial catches in Fortune Bay and Placentia Bay on the south coast; Bay of Islands on the west coast; Notre Dame Bay on the 'east coast; and Frenchman's Island on the coast of Labrador.

2. Average lengths varied from 32.4 centimetres in Notre Dame Bay to 36.4 centimetres in Labrador (Table II).

3. The population in each area differed in year-class composition. The oldest herring were taken on the coast of Labrador in 1943 (average age 11.88 yr.), and the youngest were from Notre Dame Bay in 1942 (7.37 yr.).

4. Growth in length differs between all areas except for Notre Dame Bay and Labrador (Fig. 3).

5. The "diameter" of the first-year growth of scales is greatest in herring from Fortune Bay, intermediate in herring from Bay of Islands and lowest in herring from Notre Dame Bay and Labrador (Fig. 4).

6. Development of the testes of male herring is farther advanced in the early part of the season than the development of the ovaries (Table III).

7. Spawning takes place between May 12 and June 3 in Fortune Bay: between May 24 and June 16 in Bay of Islands; and between June 5 and June 20 in Notre Dame Bay (Table IV). No spawning has been observed on the coast of Labrador.

8. Air temperatures at localities near the spawning grounds suggest that spawning takes place under progressively higher temperature conditions from south to north.

9. Mean vertebral counts are similar within the areas investigated, indicating that there is a single homogeneous population of herring in each area. Between areas, however, with the exception of Notre Dame Bay and Labrador, there are statistically significant differences in mean vertebral counts and it is, therefore, very probable that the populations are discrete.

10. The herring fisheries in Newfoundland can be increased considerably. Present catches consist chiefly of very large and old herring indicating low, total mortality rates for all populations.

ACKNOWLEDGMENTS

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Relationship of Otolith Lengths and Weights in the Haddock *Melanogrammus aeglefinus* (L.) to the Rate of Growth of the Fish[1]

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ABSTRACT

Haddock otolith lengths decline from over 5% of the total length of the fish at 14 to 17 cm. to almost 3% at 74 to 77 cm. The otolith lengths of slow-growing haddock decline less rapidly than those of fast-growing haddock. Little difference was found between otolith lengths in male and female haddock of the same length.

Slow-growing haddock both from the Grand Bank and from St. Pierre Bank have heavier otoliths than fast-growing haddock at the same fish lengths. This is true not only for fish of different year-classes in the same year but also for fish of the same year-class in different years.

The otoliths of male haddock of the Grand Bank exceed progressively in weight the otoliths of females of the same length after the males become sexually mature. The relative increase in otolith weight of the male fish is attributed to a probably slower growth rate after sexual maturity, which occurs earlier than in females. Similarly, the heavier otoliths of mature fish in sizes overlapping with immature fish are due to a greater age of the mature fish at these sizes. Otolith weight relative to fish weight decreased considerably with increase in fish size, and no distinct differences were apparent between otolith weights as a percentage of fish weights in slow-growing and fast-growing fish of the same length.

<div style="text-align:center">CONTENTS</div>

INTRODUCTION

WORK on otolith lengths and weights in the haddock *Melanogrammus aeglefinus* (L.) was begun in 1947 in an attempt to use these features of the otoliths in differentiating between haddock populations on various banks. The present paper attempts to describe the methods used, and to establish the fact that rate of growth of the fish affects the ratio of the length and weight of its otoliths to the total length of the fish. Fish otoliths contain only small percentages of water and organic matter (Lunde, 1929; Vinogradov, 1953), can be cleaned, dried, and weighed with great accuracy, and they are collected in any case for age readings. If differences can be found to exist in the weight of otoliths at a given fish length in different areas, otolith weights can be useful in the separation of fish populations. For this purpose they are much more convenient to use than the rather crude weights of wet fish which are obtained in various stages of leaching and drainage. In many fishes, in which accurate age reading is doubtful, otolith weights, which are more factual, may offer a better separation of fish populations than growth rates which are dependent on the judgment of the scale- or otolith-reader.

METHODS

GENERAL

The length of the fish in the fresh round condition was measured to the nearest centimetre from the tip of the snout to the end of the mid-fork of the caudal fin. The measuring board used had lines at the half-centimetre positions so that the even centimetre position fell in the middle of a space. Lengths which ended on a line were assigned to the following interval.

The otoliths used were typically from random samples of haddock. Both otoliths were removed, washed in fresh water, wiped with a cloth and placed in envelopes. They were stored at room temperature for one year before being measured or weighed.

Haddock ages were read by the senior author from scales, and up to 8 or 9 years of age were distinct enough and compared well enough with otolith readings to be considered approximately correct. The age-reader had no knowledge of the otolith weights.

The stages of sexual maturity were as a rule checked by the senior author from samples examined in the laboratory. These formed a large part of the collection. Adequate comparisons and checks were carried out between sizes at sexual maturity in samples examined at sea and at the station.

The Grand Bank area from which otoliths were taken includes the Grand Bank south of 45°N. latitude and from the eastern slope of the bank to 54°W. longitude.

The St. Pierre Bank area for purposes of this paper is bounded by five lines: on the east by the 55°10′W. longitude line; on the north by the 47°N. latitude line; on the west by the 57°30′W. longitude line; on the south by the 44°30′N. latitude line; and the fifth line extends NW.–SE. along the Laurentian

Channel, beginning at Lat. 46°00'N., Long. 57°30'W. and ending at 44°30'N., 56°15'W. All areas included in this definition which are within 12 nautical miles of the shore line are excluded from the St. Pierre Bank area.

OTOLITH LENGTH MEASUREMENT AND ESTIMATED ACCURACY

Otoliths were measured to the nearest tenth of a millimetre, using vernier calipers. The greatest length of both otoliths from each fish was measured, and the average length of the two was changed to a percentage of the total length of the fish from the snout to the end of the mid-fork of the caudal fin. These individual percentages were used in computing the averages in Tables II-V. Otoliths crystallized at one or both ends were not measured. Repeats of original measurements by the same person and by another measurer, with the original measurements unknown to the repeaters, have shown that the error in otolith measurement is less than 0.1 mm.

OTOLITH WEIGHT MEASUREMENT AND ESTIMATED ACCURACY

Otolith weights were determined on an Oertling aperiodic assay balance with a sensitivity of 0.0002 gram. The accuracy of the balance was checked against certified weights and the necessary adjustments were made before and during each day's weighing.

The weighings were carried out mostly by F. Brett and E. L. Rowe, and the earlier weighings by the junior author. Many checks were made on the accuracy of the weighings and all otoliths showing unusual weights were checked again. No partly or wholly crystallized otoliths and no broken or chipped otoliths were weighed. Both otoliths were weighed in 89% of the cases and in the remainder one otolith was weighed and the weight doubled. All the material is presented as the weight of both otoliths. Forceps were used to handle the otoliths during the weighing procedure.

Although all weighings of the various samples were done one year after collection, they took place in different years and at different times in the year. A number of test weighings of otoliths for weight change was carried out, therefore, in order to determine what weight changes would occur if the otoliths were left for a longer period in the laboratory before weighing or if they were dried to a constant weight in an oven.

Table I shows the result in two separate experiments of weighings of haddock otoliths two, three, four and five years after the first weighing and also after five separate periods of drying in a vacuum oven. The latter drying at 62°C. (144°F.) in the vacuum oven was carried out for a total period of 110 hours in five periods, with the otoliths in a desiccator between oven dryings. They were allowed to cool to room temperature in a desiccator before weighing. It will be noted that after the first year of storage there was no further loss of weight in the additional storage period of four and five years. Actually, there was a slight gain in weight ranging from 0.01 to 0.15% in 10 out of 11 otolith sets. There is naturally some adjustment of water content of laboratory-stored otoliths to the moisture content of the air. In the oven drying (in 110 hours

TABLE I.—Repeated weighings of haddock otoliths. Percentage increase (+) or decrease (−) from first weighing

Group 1. Taken June 13, 1947, southwest slope Grand Bank, 44° 16′ N., 52° 18′ W., 52 fathoms.

Average length of fish	No. of pairs of otoliths	Range of weight of two otoliths	1st wt. after 1 yr. natural drying in air June 22 1948	Average weight of two otoliths								Actual loss in weight by Sept. 8, 1953, from first weighing in 1948
				Percentage decrease (−) or increase (+) from first weighing								
				Natural drying in air		Oven drying under vacuum Percentage decrease (−) or increase (+) from first annual weighing						
				June 17 1951	April 20 1953	Aug. 8 1953 (12 hrs.)	Aug. 10 1953 (12 hrs.)	Aug. 18 1953 (60 hrs.)	Sept. 7 1953 (12 hrs.)	Sept. 8 1953 (14 hrs.)		
cm.		g.	g.	%	%	%	%	%	%	%		mg.
42	14	0.5000–0.6999	0.6030	+0.030	+0.149	−0.083	−0.050	−0.083	−0.066	−0.050		0.3
47	32	0.7000–0.8999	0.7920	+0.063	+0.088	−0.063	−0.038	+0.076	+0.068	−0.076		0.6
50	20	0.9000–1.0999	0.9877	−0.010	+0.030	−0.101	−0.081	−0.122	−0.122	−0.132		1.3
56	14	1.1000–1.2999	1.1932	+0.059	+0.025	−0.126	−0.109	−0.092	−0.101	−0.126		1.5
59	9	1.3000–1.5999	1.3949	+0.079	+0.043	−0.093	−0.086	−0.079	−0.100	−0.108		1.5

Group 2. Taken April 24, 1948, St. Pierre Bank, 46° 54′ 30″ N., 57° 00′ 15″ W., 96–104 fathoms.

			April 28 1949	June 19 1951	April 20 1953	Aug. 8 1953 (12 hrs.)	Aug. 10 1953 (12 hrs.)	Aug. 18 1953 (60 hrs.)	Sept. 7 1953 (12 hrs.)	Sept. 8 1953 (16 hrs.)		Actual loss in weight by Sept. 8, 1953, from first weighing in 1949
40	13	0.5000–0.6999	0.6198	+0.081	+0.067	−0.048	0.000	−0.065	−0.081	−0.129		0.8
47	26	0.7000–0.8999	0.7831	+0.026	+0.026	−0.089	−0.089	−0.140	−0.140	−0.166		1.3
57	12	0.9000–1.2999	1.1193	+0.027	+0.027	−0.098	−0.098	−0.107	−0.107	−0.125		1.4
65	21	1.3000–1.5999	1.4350	+0.021	+0.014	+0.111	−0.125	−0.132	−0.132	−0.160		2.3
67	9	1.6000–1.8999	1.7092	−0.018	−0.029	−0.140	−0.146	−0.181	−0.170	−0.199		3.4
73	6	1.9000–2.2999	2.0853	+0.019	+0.010	−0.096	−0.149	−0.230	−0.144	−0.182		3.8

drying) the losses from the original weights ranged from 0.05 to 0.13% (0.3 to 0.8 mg. per pair of otoliths) at the smaller sizes to 0.18 to 0.20% (3.4 to 3.8 mg. per pair of otoliths) at the larger. Since many of the groups had reached an approximately constant weight by this time, and since the differences between otolith average weights, forming the basis of the argument in this paper, are mostly of the magnitude of 50 to 150 mg. or 5 to 10 or more per cent, it did not seem to be important to make a further study of otolith weight loss. Moreover, the haddock otoliths compared in detail in this present paper were almost all from the smaller sized haddock, and these usually had considerably less than the maximum otolith weight losses in the vacuum oven.

OTOLITH LENGTHS

OTOLITH LENGTHS IN HADDOCK OF THE SAME LENGTH BUT OF DIFFERENT AGES

A significant feature of the haddock otolith as indicated in Figures 1 and 2 and in Tables II–V is its gradual decline in length relative to the fish length. The otolith length is over 5% of the total length of the fish at sizes between 14 and 17 cm. and falls almost as low as 3% at 74 to 77 cm. (Table IV). Although there is considerable variability in the averages owing to the small numbers of fish at some of the compared lengths, it is evident that older haddock have longer otoliths than younger haddock at the same fish lengths (Fig. 1 and 2, Tables II and III). In this regard, compare especially the considerable differences between relative lengths of otoliths in fish of the same length from ages 3 and
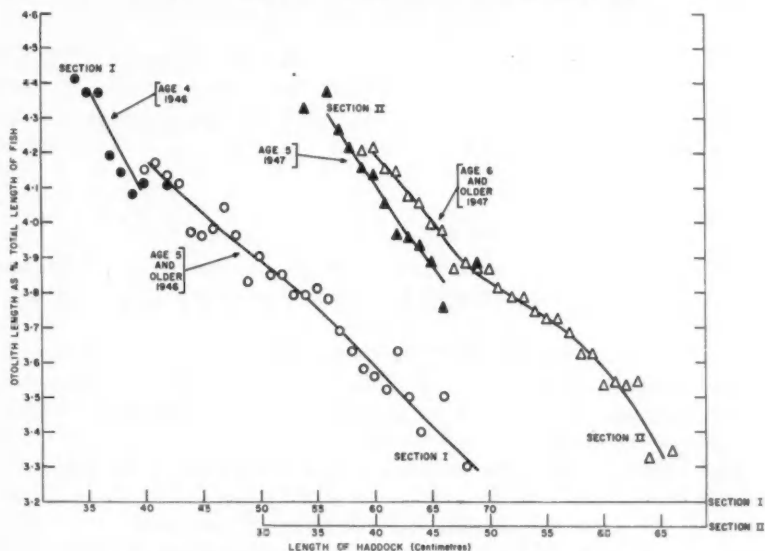

FIG. 1.—Relative length of the otolith in Grand Bank haddock of different sizes and ages (averages from less than 3 fish omitted).
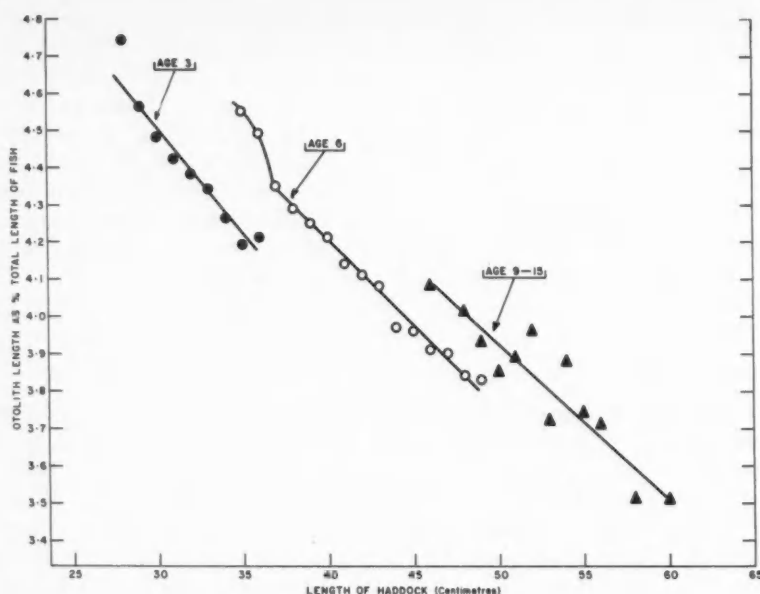
FIG. 2.—Relative length of the otolith in 3, 6 and 9–15 year old haddock from the Grand Bank in 1955 (averages from less than 5 fish omitted).

6 yr. and of ages 6 and 9–15 yr. in Figure 2; also the very large differences which would be evident if the age 3 yr. line in this figure were projected to overlap with the age 9–15 yr. line. Otolith lengths, therefore, offer a possible means of distinguishing between haddock populations whose growth characteristics are different.

OTOLITH LENGTHS IN MALE AND FEMALE HADDOCK

In Tables IV and V the average otolith length as a percentage of fish length is compared in male and female haddock from the Grand Bank and from St. Pierre Bank.

Judging from the comparison of otolith weights in male and female haddock which is given later in this paper, significant differences would not be expected until the male fish have become mature and have had differential slowing of growth as compared with the female haddock.

From Tables IV and V the evidence is mildly in favour of the idea that the otoliths of male haddock on the average are slightly longer than those of female haddock of the same fish length. The difference, if one exists, is small and variable and cannot be of great significance in the comparison of otolith lengths of haddock populations from different areas.

TABLE II.—Relative length of the otolith in the 1942 year-class and in older haddock of the Grand Bank in 1946 and 1947.   (Values in parentheses are numbers of fish.)

| Total length of fish | Average of ratio of otolith length to fish length, as percentage | | | |
| | 1942 year-class | | Year-classes older than 1942 | |
	4 yr. old 1946	5 yr. old 1947	Older than 4 yr. 1946	Older than 5 yr. 1947
cm.				
31	4.45 (1)	...	...	...
32	4.63 (2)	...	...	...
33	4.55 (1)	4.70 (1)	...	...
34	4.41 (7)	4.32 (3)	4.56 (1)	...
35	4.37 (12)	...	...	...
36	4.37 (13)	4.37 (10)	4.39 (1)	...
37	4.19 (12)	4.26 (22)	4.35 (2)	4.65 (1)
38	4.14 (16)	4.21 (25)	4.47 (1)	4.26 (2)
39	4.08 (12)	4.15 (31)	4.31 (1)	4.20 (3)
40	4.11 (10)	4.13 (28)	4.15 (6)	4.21 (9)
41	3.93 (1)	4.05 (30)	4.17 (3)	4.15 (12)
42	4.11 (4)	3.96 (32)	4.13 (5)	4.14 (18)
43	...	3.95 (16)	4.11 (4)	4.07 (24)
44	...	3.93 (10)	3.97 (8)	4.05 (27)
45	...	3.88 (10)	3.96 (11)	3.99 (32)
46	...	3.75 (7)	3.98 (9)	3.97 (33)
47	3.77 (1)	3.79 (1)	4.04 (18)	3.86 (36)
48	...	...	3.96 (17)	3.88 (47)
49	4.06 (1)	3.88 (3)	3.83 (13)	3.86 (50)
50	...	...	3.90 (13)	3.86 (41)
51	...	...	3.85 (18)	3.80 (50)
52	...	3.41 (1)	3.85 (18)	3.78 (45)
53	...	...	3.79 (19)	3.78 (59)
54	...	...	3.79 (21)	3.74 (55)
55	...	...	3.81 (30)	3.72 (49)
56	...	...	3.78 (24)	3.72 (37)
57	...	...	3.69 (24)	3.68 (44)
58	...	...	3.63 (10)	3.62 (38)
59	...	...	3.58 (12)	3.62 (25)
60	...	...	3.56 (13)	3.53 (10)
61	...	...	3.52 (11)	3.54 (15)
62	...	...	3.63 (8)	3.53 (13)
63	...	...	3.50 (8)	3.54 (9)
64	...	...	3.40 (5)	3.32 (3)
65	...	...	3.48 (2)	3.28 (1)
66	...	...	3.50 (3)	3.34 (5)
67	...	...	3.75 (1)	3.21 (2)
68	...	...	3.30 (6)	...
69	...	...	3.13 (1)	...
70	...	...	3.24 (2)	3.27 (1)
74	...	...	...	...

TABLE III.—Relative length of the otolith in 3, 6 and 9–15 year old haddock of the Grand Bank in 1955. (Numbers in parentheses are numbers of fish.)

Length of fish	Average of ratio of otolith length to fish length, as percentage		
	3 yr. old	6 yr. old	9–15 yr. old
cm.			
26	4.81 (1)	...	...
28	4.74 (11)	...	...
29	4.56 (21)	...	...
30	4.48 (27)	...	...
31	4.42 (38)	...	...
32	4.38 (42)	...	...
33	4.34 (44)	...	...
34	4.26 (20)	4.41 (1)	...
35	4.19 (13)	4.55 (6)	...
36	4.21 (6)	4.49 (13)	...
37	4.31 (1)	4.35 (31)	...
38	...	4.29 (36)	...
39	...	4.25 (72)	4.41 (1)
40	...	4.21 (73)	...
41	...	4.14 (84)	...
42	...	4.11 (89)	...
43	...	4.08 (61)	...
44	...	3.97 (59)	4.22 (1)
45	...	3.96 (41)	4.44 (1)
46	...	3.91 (31)	4.08 (5)
47	...	3.90 (13)	4.06 (4)
48	...	3.84 (9)	4.01 (7)
49	...	3.83 (5)	3.93 (9)
50	...	3.84 (4)	3.85 (9)
51	...	...	3.89 (10)
52	...	3.86 (1)	3.96 (6)
53	...	3.70 (3)	3.72 (10)
54	...	...	3.88 (13)
55	...	...	3.74 (10)
56	...	...	3.71 (5)
57	...	...	3.54 (2)
58	...	...	3.51 (6)
59	...	...	3.68 (3)
60	...	3.27 (1)	3.51 (6)
61	...	...	3.53 (3)
62	...	...	3.51 (4)
63	...	...	3.33 (1)
64	...	...	3.54 (1)

TABLE IV.—Relative length of the otolith in male and in female haddock from the Grand Bank and St. Pierre Bank, 1946 to 1948. (In addition to the haddock of Table I a relatively small number of haddock obtained in 1948 are included in this Table. Numbers in parentheses are numbers of fish.)

Length range of fish	Percentage mature				Ratio of otolith length to total fish length, as percentage			
	Grand Bank		St. Pierre Bank		Grand Bank		St. Pierre Bank	
	Males	Females	Males	Females	Males	Females	Males	Females
cm.								
14–15	...	...	0 (2)	...	...	...	5.43	...
16–17	...	...	0 (2)	0 (2)	...	...	5.06	5.10
18–19	...	...	0 (9)	0 (1)	...	...	4.74	4.68
20–21	...	...	0 (8)	0 (1)	...	...	4.74	5.00
22–23	...	...	0 (10)	0 (3)	...	...	4.86	4.94
24–25	...	...	0 (17)	0 (4)	...	...	4.64	4.67
26–27	...	...	0 (4)	0 (2)	...	...	4.56	4.43
28–29	...	...	...	0 (2)	...	...	...	4.31
30–31	0 (1)	...	...	...	4.45	...	...	...
32–33	0 (2)	0 (5)	...	...	4.46	4.54	...	...
34–35	8 (12)	0 (16)	...	0 (2)	4.41	4.33	...	4.55
36–37	14 (43)	0 (21)	0 (3)	0 (2)	4.30	4.28	4.31	4.22
38–39	26 (50)	0 (42)	0 (4)	0 (2)	4.18	4.16	4.34	4.24
40–41	44 (57)	5 (56)	57 (7)	0 (8)	4.11	4.13	4.08	4.17
42–43	52 (66)	22 (72)	63 (8)	14 (7)	4.05	4.02	4.02	4.13
44–45	88 (64)	36 (64)	33 (15)	0 (14)	4.05	3.95	3.86	3.90
46–47	85 (72)	55 (53)	53 (17)	8 (13)	3.94	3.91	3.77	3.84
48–49	96 (82)	78 (65)	69 (16)	17 (18)	3.88	3.86	3.70	3.71
50–51	96 (67)	84 (62)	100 (2)	10 (10)	3.87	3.79	3.80	3.65
52–53	98 (86)	97 (64)	71 (7)	60 (10)	3.80	3.78	3.69	3.60
54–55	94 (88)	94 (70)	100 (4)	50 (4)	3.77	3.73	3.56	3.54
56–57	94 (53)	98 (81)	100 (7)	50 (4)	3.70	3.71	3.66	3.46
58–59	100 (26)	100 (65)	100 (10)	100 (10)	3.59	3.64	3.59	3.57
60–61	100 (6)	98 (48)	100 (14)	100 (5)	3.68	3.54	3.62	3.49
62–63	100 (4)	100 (34)	100 (7)	100 (8)	3.51	3.55	3.51	3.49
64–65	100 (3)	100 (8)	100 (8)	100 (9)	3.34	3.40	3.42	3.33
66–67	100 (3)	100 (9)	100 (6)	100 (5)	3.34	3.40	3.40	3.36
68–69	100 (1)	100 (6)	100 (7)	100 (10)	3.50	3.24	3.29	3.14
70–71	...	100 (3)	100 (1) .	100 (5)	...	3.25	3.34	3.23
72–73	...	...	...	100 (6)	...	...	...	3.29
74–75	...	100 (1)	...	100 (2)	...	3.00	...	3.14
76–77	...	...	...	100 (4)	...	...	...	3.08

Table V.—Relative length of the otolith in male and in female haddock from the Grand Bank in 1955.

Fish length range	Total haddock 3, 6 and 9–15 years old					
	Number of fish		Percentage mature		Ratio of otolith length to fish length, as percentage	
	Male	Female	Male	Female	Male	Female
cm.						
26–27	. . .	1	. . .	0	. . .	4.81
28–29	18	14	0	0	4.65	4.59
30–31	32	33	3	0	4.46	4.44
32–33	44	42	2	0	4.34	4.38
34–35	16	24	6	0	4.31	4.27
36–37	39	12	77	42	4.40	4.25
38–39	81	28	86	50	4.26	4.27
40–41	87	70	98	54	4.16	4.18
42–43	70	80	91	70	4.09	4.10
44–45	40	62	100	89	3.98	3.97
46–47	15	38	100	82	4.01	3.90
48–49	14	16	93	100	3.96	3.86
50–51	15	8	93	100	3.87	3.86
52–53	11	9	100	100	3.89	3.68
54–55	15	8	100	100	3.78	3.89
56–57	2	5	100	100	3.52	3.72
58–59	2	7	100	100	3.62	3.55
60–61	1	9	100	100	3.43	3.49
62–63	2	3	100	100	3.57	3.41
64–65	. . .	1	. . .	100	. . .	3.54

OTOLITH WEIGHTS

OTOLITH WEIGHTS IN HADDOCK OF THE SAME LENGTH, IN THE SAME YEAR, FROM YOUNGER AND FROM OLDER YEAR-CLASSES

GRAND BANK. Figure 3 and Table VI show the average weight of both otoliths for fish of various lengths in the 1942 year-class (4 years old in 1946, 5 years old in 1947, etc.) compared with the otolith weights of all the older year-classes combined. The samples of otoliths considered were collected in the years 1946 to 1950 and mostly in the January to June period. In Figure 3, sight curves have been drawn to the points plotted. The numbers from which each average was made up were placed on the graph and each curve was weighted accordingly. The graphs of 1948, the upper ends of the two curves for the older fish in 1949, and the curve for the oldest year-classes in 1950 are weak and the points variable from lack of numbers. With a few exceptions, usually from small samples, the average weights of otoliths from the older fish are consistently greater than those from younger fish of the same length. This is most clearly evident in the wide difference between the overlapping portion of the curves representing the 4-year-old 1946 year-class (squares) and the 8-year-old 1942 year-class (solid circles) in Section V of Figure 3. The gap of 4 years makes a difference of over 100 mg. in otolith weight among fish of the two year-classes
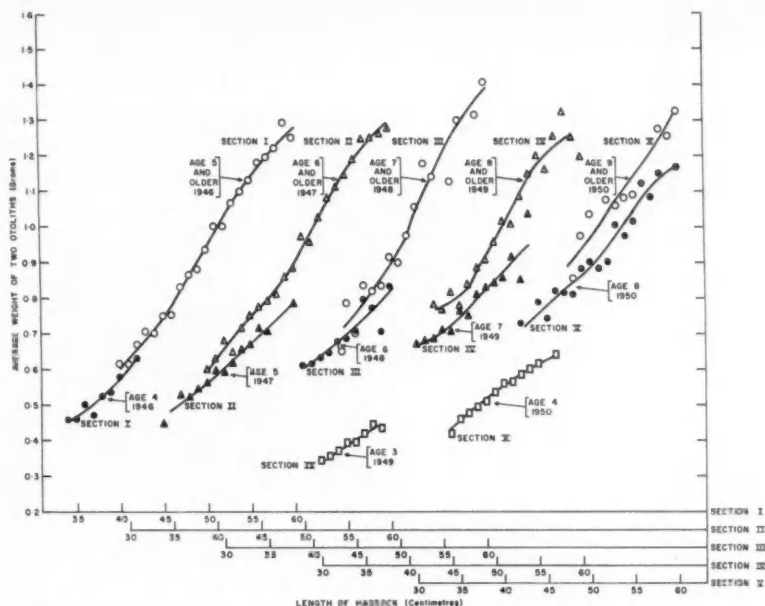
FIG. 3.—Average total weight of both otoliths at various sizes and ages for Grand Bank haddock (averages from less than 3 fish omitted).

in the 42–46 cm. length range. This is more than a 15% difference. A similar difference is indicated in the widely different trends of the curves for the 3-year-old (squares) and the 7-year-old (solid circles) fish in Figure 3, Section IV.

ST. PIERRE BANK. In Figure 4 and Table VII the weights of the otoliths of the 1942 year-class on St. Pierre Bank in each of four years are compared at various fish lengths with those of older year-classes. From other indications, such as different relative abundance of the year-classes, the St. Pierre Bank haddock stock appears to be essentially separate from the Grand Bank stock. The number of samples from St. Pierre Bank was much less than from the Grand Bank. In spite of this, considerable differences are evident on this bank also between the weights of otoliths from the younger and the older year-classes at the same fish length.

The otoliths of the older St. Pierre Bank haddock were considerably heavier than those of fish of the same length from the 1942 year-class. At the same time there is less overlapping in the lengths of fish of different year-classes in these samples. The reason is, that, while from 1946 to 1949 the 1942 year-class formed almost 50% of the haddock catch on St. Pierre Bank, the year-classes 1939–1941 averaged less than 3% each, while the older year-classes, 1936–1938, averaged 6% to 10% of the catch. Thus, many of the otolith weights for fish of the same length are 4 or more years apart on this bank.

TABLE VI.—Numbers of haddock and of otolith pairs and average of total weights of both otoliths in Grand Bank haddock of the 1942 and of older year-classes, and of the 1946 year-class in successive years, 1946 to 1950 (30–60 cm. only). (Numbers in parentheses are numbers of fish.)

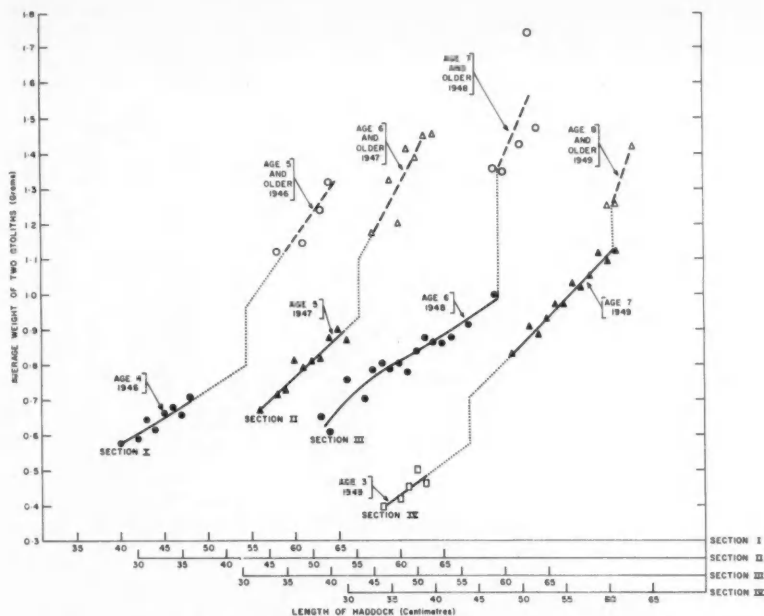| Length of fish	1946 Average weight		1947 Average weight		1948 Average weight		1949 Average weight			1950 Average weight		
	4 yr.	5 yr. & older	5 yr.	6 yr. & older	6 yr.	7 yr. & older	3 yr.	7 yr.	8 yr. & older	4 yr.	8 yr.	9 yr. & older
cm.	g.	g.	g.	g.	g.	g.	g.	g.	g.	g.	g.	g.
30	.3471 (1)						.3441 (6)			.3676 (1)		
31	.4243 (2)						.3564 (15)			.3808 (2)		
32	.4104 (1)						.3708 (16)			.4880 (1)		
33	.4545 (8)						.3930 (14)			.4193 (4)		
34	.4563 (12)	.5084 (1)	.5134 (1)				.3946 (26)			.4607 (21)		
35	.4983 (13)	.5398 (1)	.4402 (3)				.4186 (12)			.4779 (20)		
36	.4719 (12)	.5380 (2)	.4872 (1)		.5312 (1)		.4445 (15)			.4948 (33)		
37	.5244 (15)	.5647 (2)	.5283 (10)	.6092 (1)	.5698 (1)		.4330 (9)			.5106 (45)		
38	.5355 (13)	.6128 (1)	.5228 (22)	.5390 (2)	.5806 (4)		.4412 (1)	.5862 (1)		.5364 (46)		
39	.5790 (11)	.6138 (6)	.5426 (25)	.5985 (3)	.6147 (5)		.5022 (1)	.6000 (1)		.5613 (31)		
40			.5637 (31)	.6282 (9)	.6304 (8)	.6788 (1)			.7364 (1)			
41	.5865 (3)	.6158 (3)	.5969 (28)	.6792 (11)	.6485 (14)	.7415 (2)	.4830 (1)	.6702 (6)	.7353 (2)	.5636 (25)	.7300 (3)	
42	.6288 (4)	.6681 (4)	.5919 (30)	.6476 (18)	.6773 (11)	.6739 (4)		.6815 (26)	.7817 (3)	.5844 (36)	.6420 (4)	
43		.7052 (4)	.6156 (31)	.7142 (24)	.6836 (17)	.7877 (4)		.6868 (31)	.7668 (3)	.6014 (17)	.7888 (4)	
44		.7014 (8)	.6554 (16)	.7527 (27)	.7101 (17)	.7083 (8)		.7102 (38)	.8149 (12)	.6161 (5)	.7421 (11)	
45		.7487 (11)	.7131 (10)	.7758 (32)	.7946 (9)	.8357 (5)		.7071 (41)	.7785 (12)	.6898 (1)	.8199 (12)	.8780 (1)
46		.7532 (9)	.7069 (7)	.7924 (33)	.7708 (7)	.8171 (5)		.7625 (50)	.8373 (14)	.6389 (1)	.8135 (26)	.9312 (2)
47	.7137 (1)	.8318 (18)	.7308 (1)	.8095 (36)	.7071 (6)	.8345 (8)		.7500 (55)	.8638 (14)	.6464 (1)	.8081 (22)	.8554 (4)
48		.8645 (17)		.8584 (47)	.8323 (6)	.9148 (5)		.8099 (38)	.9085 (26)		.8830 (30)	.9730 (4)
49	.8509 (1)	.8797 (13)	.7869 (3)	.8828 (50)	.9371 (1)	.8980 (4)		.8306 (25)	.9585 (21)		.9017 (14)	1.0350 (4)
50		.9352 (12)		.9708 (40)				.8426 (13)				
51		1.0003 (17)	.7439 (1)	.9550 (49)	.9039 (1)	.9742 (3)		.8562 (9)	1.0138 (24)		.8848 (20)	.9040 (1)
52		1.0019 (19)		1.0247 (44)	1.0590 (1)	1.0578 (9)		.9134 (7)	1.0067 (15)		.9002 (12)	1.0772 (8)
53		1.0672 (19)		1.0791 (58)	1.0372 (1)	1.1788 (3)		1.0359 (3)	1.0826 (21)		1.0050 (12)	1.0594 (8)
54		1.0995 (21)		1.1095 (55)		1.1393 (4)			1.1444 (19)		.9755 (10)	1.0797 (10)
55		1.1333 (30)		1.1445 (49)		1.0702 (1)			1.2014 (26)		1.0141 (7)	1.0918 (5)
56		1.1808 (24)		1.1808 (37)	.8753 (1)	1.1263 (4)		1.0672 (1)	1.1603 (8)		1.1217 (3)	1.3043 (2)
57		1.1970 (24)		1.2453 (43)		1.2990 (6)		1.2354 (1)	1.2504 (11)		1.0825 (4)	1.2851 (2)
58		1.2233 (10)		1.2480 (37)		1.2675 (2)		1.2202 (1)	1.3213 (10)		1.1502 (6)	1.2755 (5)
59		1.2936 (12)		1.2082 (25)		1.3141 (4)			1.2516 (6)		1.4008 (1)	1.2567 (3)
60		1.2507 (13)		1.2750 (10)		1.4080 (5)			1.1943 (6)		1.1675 (3)	1.3267 (4)

FIG. 4.—Average total weight of both otoliths at various sizes and ages for St. Pierre Bank haddock (averages from less than 3 fish omitted).

On the Grand Bank, on the other hand, while the 1942 year-class averaged about 35% of the catch in the years 1946 to 1950, in the same years the 1940 and 1941 year-classes included 11% and 14% respectively, while some of the older year-classes contained fairly substantial though rapidly decreasing percentages of the catch. Thus, on this bank there was more overlapping of the 1942 year-class with neighbouring older year-classes in length, and the differences in otolith weights at the same fish length, between the 1942 and the older year-classes, were on the whole smaller than on St. Pierre Bank.

OTOLITH WEIGHTS IN HADDOCK OF THE 1942 YEAR-CLASS

In addition to comparing the otolith weights of the 1942 year-class with those of the sum of all older year-classes, the average weights of the otoliths at each fish length of the 1942 year-class have been compared at ages between 4 and 8 for the Grand Bank and 4 and 7 for St. Pierre Bank.

GRAND BANK. Figure 5 and Table VI show the otolith weights at different lengths and ages of the 1942 year-class haddock from the Grand Bank. To avoid crowding the figure, the scanty 6-year-old group of the 1942 year-class has not been shown. Also, since variability in otolith weights increases with fish age and length, the otolith weights at the same sizes of the 7- and 8-year-olds have been combined and averaged.

TABLE VII.—Numbers of haddock and of otolith pairs and average total weights of both otoliths in St. Pierre Bank haddock of the 1942 and of older year-classes and of the 1946 year-class in successive years, 1946 to 1949 (30–64 cm. only).   (Numbers in parentheses are numbers of fish.)

Length of fish	1946		1947		1948		1949		
	Average weight		Average weight		Average weight		Average weight		
	4 yr.	5 yr. and older	5 yr.	6 yr. and older	6 yr.	7 yr. and older	3 yr.	7 yr.	8 yr. and older
cm.	g.	g.	g.	g.	g.	g.	g.	g.	g.
30	...	...	...	...	...	...	.4032 (1)	...	...
31	...	...	...	...	...	...	...	...	...
32	...	...	...	...	...	...	.3320 (1)	...	...
33	...	...	...	...	...	...	.3420 (2)	...	...
34	.4576 (1)	...	...	...	.4846 (1)	...	.3973 (6)	...	...
35	...	...	...	...	...	...	.3957 (2)	...	...
36	.5394 (1)	...	.5040 (1)	...	.5506 (2)	...	.4190 (9)	...	...
37	.4180 (1)	...	...	...	.5449 (1)	...	.4543 (1)	...	...
38	.4740 (1)	...	...	...	.6314 (1)	...	.5028 (4)	...	...
39	.5683 (1)	...	...	...	.6538 (3)	...	.4639 (3)	...	...
40	.5774 (3)	...	.6347 (1)	...	.6104 (6)	...	...	...	...
41	.5280 (2)	...	.6182 (2)	.7960 (1)	...	.6890 (1)	.4960 (1)	.7020 (1)	...
42	.5917 (3)	...	.6456 (2)	...	.7580 (3)	.7190 (1)	...	...	...
43	.6442 (3)	...	.6242 (2)	...	.6364 (1)	...	...	...	...
44	.6154 (10)	...	.6721 (9)	...	.7030 (4)	...	...	.7577 (2)	...
45	.6627 (4)	...	.8150 (1)	...	.7846 (6)	...	...	.7664 (4)	...
46	.6819 (12)	...	.7151 (10)	...	.8044 (6)	...	...	.7732 (2)	...
47	.6608 (5)	1.0031 (1)	.7285 (7)	...	.7887 (7)	...	...	.6940 (1)	...
48	.7116 (8)	.7751 (1)	.8126 (10)	...	.8032 (9)	.9660 (1)	...	.8735 (1)	...
49	.6586 (2)	...	.7931 (17)	...	.7813 (3)	...	...	.8309 (4)	...
50	...	...	.8113 (3)	...	.8391 (10)	1.1526 (1)	...	.9469 (2)	...
51	...	.8520 (1)	.8172 (5)	.8323 (1)	.8754 (9)	1.0049 (1)	...	.9079 (3)	...
52	...	...	.8779 (8)	1.0138 (1)	.8653 (12)	...	...	.8849 (3)	...
53	...	.9943 (1)	.8997 (5)	.9964 (1)	.8604 (7)	1.1412 (2)	...	.9314 (13)	1.0252 (1)
54	...	.8664 (1)	.8729 (3)	.9681 (1)	.8823 (4)	...	...	.9722 (15)	1.3523 (1)
55	...	...	.8240 (2)	1.1578 (2)	1.0913 (2)	...	...	.9696 (8)	...
56	...	1.1100 (2)	...	1.2726 (2)	.9158 (4)	1.0485 (2)	...	1.0320 (16)	...
57	...	1.0333 (1)	.9049 (2)	1.1738 (4)	1.0552 (2)	1.3706 (1)	...	1.0186 (9)	...
58	...	1.1228 (4)	...	.9104 (2)	.9558 (2)	1.2876 (2)	...	1.0495 (6)	...
59	...	1.1720 (2)	...	1.3255 (7)	1.0005 (2)	1.3611 (3)	...	1.0908 (4)	1.4247 (1)
60	...	1.3013 (1)	...	1.2044 (6)	1.2790 (2)	1.3531 (8)	...	1.1165 (4)	1.2517 (3)
61	...	1.1478 (3)	1.1090 (1)	1.4142 (3)	...	1.1660 (2)	...	1.1244 (3)	1.2560 (5)
62	...	1.3899 (2)	...	1.3923 (4)	...	1.4281 (3)	...	1.2232 (2)	1.6537 (2)
63	...	1.2413 (3)	...	1.4530 (6)	...	1.7366 (3)	...	1.1999 (2)	1.4182 (6)
64	...	1.3199 (3)	...	1.4548 (5)	...	1.4731 (3)	...	...	1.3692 (1)

With due allowance for variability when numbers are small or otolith weights are large, haddock of the same length but at increasing ages in the same year-class are seen to have increasingly greater otolith weights.

ST. PIERRE BANK. In Figure 6 and Table VII the St. Pierre Bank 1942 year-class is treated similarly. Again, it is apparent that older fish of the same size in the same year-class possess heavier otoliths.

In Figures 3–6, and in Tables VI and VII it can be seen that the differences between weights of otoliths of younger and older fish of the same length are usually far greater than could result from the small differences in average fish length within a centimetre size due to different trends of the frequency curve within the centimetre size.

OTOLITH WEIGHTS IN MALE AND FEMALE HADDOCK

OTOLITH WEIGHTS IN MALE AND FEMALE HADDOCK OF THE SAME LENGTH. In Figure 7 and Table VIII the numbers of fish and the average total weight of the pairs of otoliths are shown for immature and mature male and female haddock of 31 cm. and upward in length from the Grand Bank in the years 1946 to 1950. Below 31 cm. the numbers of fish were too few to provide comparable averages,
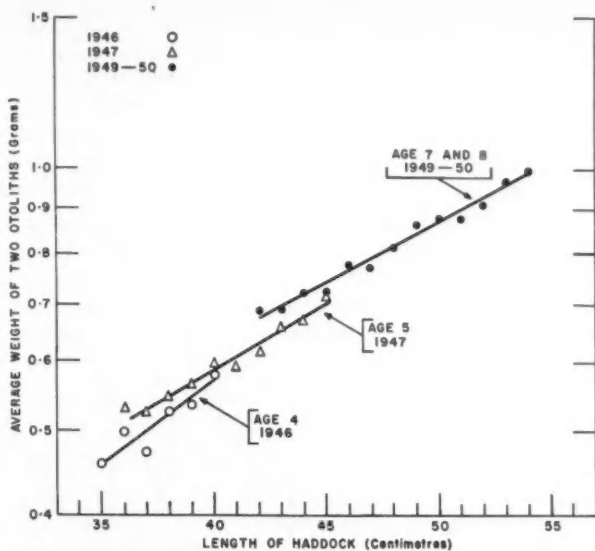
Fig. 5.—Average total weight of both otoliths at various sizes and ages of the 1942 year-class of Grand Bank haddock (Semi-log graphs. Averages from less than 10 fish omitted).
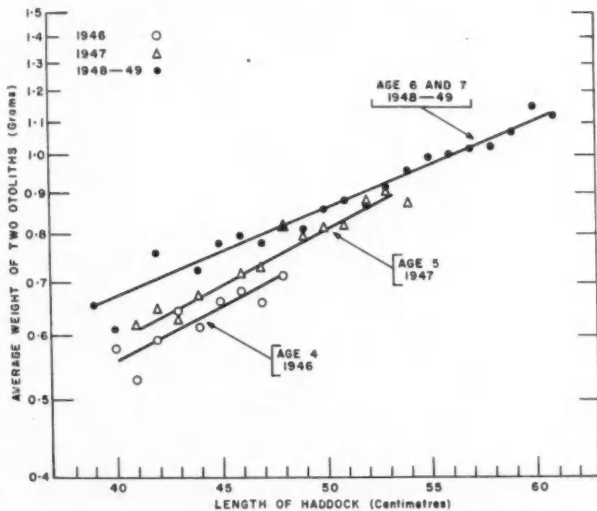

Fig. 6.—Average total weight of both otoliths at various sizes and ages of the 1942 year-class of St. Pierre Bank haddock. (Semi-log graphs. Averages from less than 2 fish at the smaller sizes and 3 fish at the larger sizes omitted).
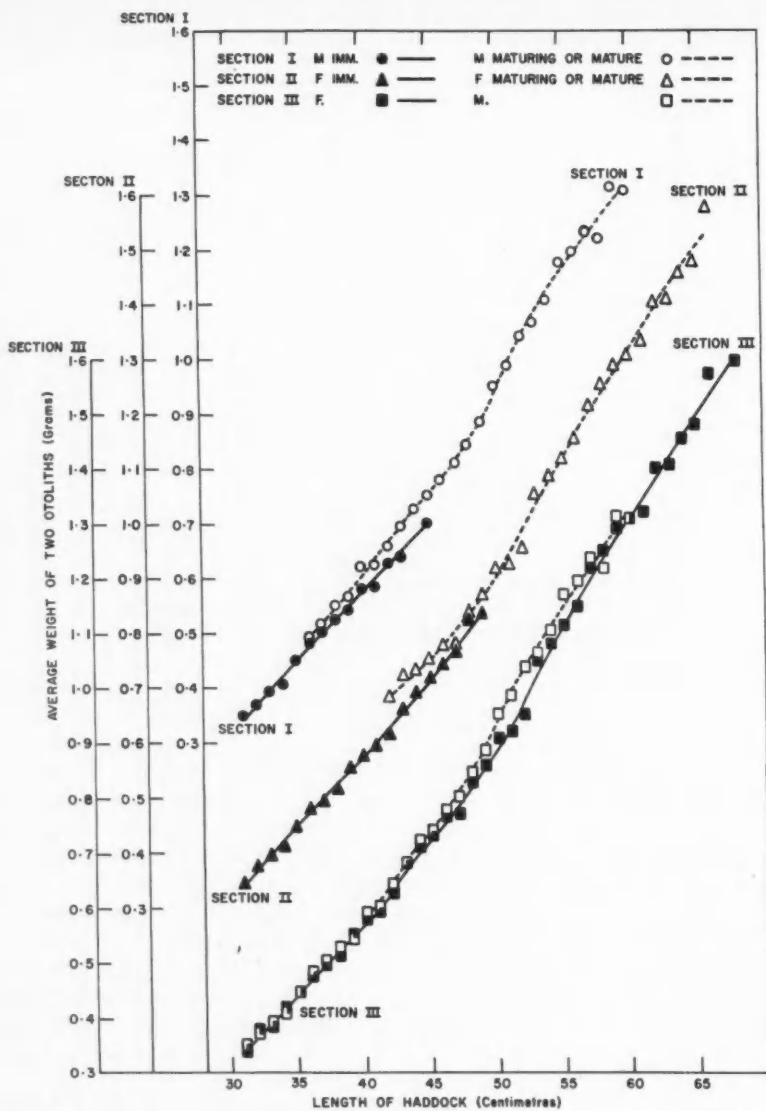
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Fig. 7.—Average weight of the two otoliths in male and female haddock from the Grand Bank. (Averages of less than 10 pairs of otoliths have been omitted.)

and above 57 cm. the numbers of male fish were too low, also, in view of the highly variable otolith weights of larger fish.

It is obvious from Figure 7 and Table VIII that mature male and female haddock possess heavier otoliths at the same fish lengths than immature male and immature female haddock respectively (Fig. 7, Sections I and II). Also, while there is little difference between the otolith weights of male and female haddock at the smaller sizes where all or most are immature, the difference gradually increases until in the larger and older mature fish the otoliths of the male haddock are on the average approximately 4% heavier than those of female haddock in the same size range (Fig. 7, Section III and Table VIII).

OTOLITH WEIGHTS RELATIVE TO FISH WEIGHTS IN MALE AND FEMALE HADDOCK. Another obvious comparison which might be used to show differences between

TABLE VIII.—Number of fish and average weights of otolith pairs from Grand Bank haddock, 1946–1950. (Numbers in parentheses are number of fish.)

Length of fish	Average weight of two otoliths						Excess of males over females		Average of percentages, M > F, in 3-cm. groups
	Male		Female		Total				
	Immature	Mature or maturing	Immature	Mature or maturing	Male	Female			
cm.	g.	g.	g.	g.	g.	g.	g.	%	
31	.3506 (15)	...	.3436 (14)	...	.3506 (15)	.3426 (14)	.0070	2.04	
32	.3689 (14)	...	.3735 (16)	...	.3689 (14)	.3735 (16)	−.0046	−1.23	0.33
33	.3944 (16)	...	.3937 (14)	...	.3944 (16)	.3927 (14)	.0007	0.18	
34	.4073 (26)	.4166 (4)	.4115 (21)	...	.4085 (30)	.4115 (21)	−.0030	−0.73	
35	.4494 (28)	.4466 (2)	.4465 (27)	...	.4492 (30)	.4465 (27)	.0027	0.60	0.19
36	.4827 (37)	.4864(4)	.4798 (30)	...	.4831 (41)	.4798 (30)	.0033	0.69	
37	.5021 (40)	.5132 (10)	.4901 (41)	...	.5043 (50)	.4901 (41)	.0142	2.90	
38	.5241 (45)	.5494 (9)	.5141 (48)	...	.5283 (54)	.5141 (48)	.0142	2.76	1.45
39	.5407 (43)	.5664 (13)	.5540 (50)	...	.5467 (56)	.5540 (50)	−.0073	−1.32	
40	.5799 (40)	.6208 (16)	.5757 (52)	.6373 (2)	.5916 (56)	.5780 (54)	.0136	2.35	
41	.5837 (30)	.6252 (31)	.5922 (44)	.7546 (1)	.6048 (61)	.5958 (45)	.0090	1.51	2.26
42	.6261 (37)	.6574 (49)	.6141 (57)	.6765 (13)	.6439 (86)	.6257 (70)	.0182	2.91	
43	.6366 (15)	.6953 (57)	.6594 (41)	.7193 (23)	.6831 (72)	.6809 (64)	.0022	0.32	
44	.6821 (4)	.7258 (60)	.6889 (30)	.7316 (29)	.7231 (64)	.7099 (59)	.0132	1.86	1.09
45	.6999 (10)	.7484 (87)	.7165 (31)	.7517 (36)	.7434 (97)	.7354 (67)	.0080	1.09	
46	.7671 (6)	.7788 (88)	.7404 (13)	.7754 (41)	.7780 (94)	.7670 (54)	.0110	1.43	
47	.8035 (7)	.8037 (95)	.7639 (25)	.7750 (58)	.8037 (102)	.7716 (83)	.0321	4.16	2.59
48	.9132 (3)	.8432 (91)	.8277(11)	.8273 (75)	.8454 (94)	.8273 (86)	.0181	2.19	
49	.8609 (1)	.8868 (91)	.8325 (11)	.8658 (73)	.8865 (92)	.8614 (84)	.0251	2.91	
50	1.0589 (2)	.9483 (56)	.8661 (8)	.9145 (54)	.9522 (58)	.9083 (62)	.0439	4.83	4.95
51	.8729 (1)	.9870 (74)	.9113 (5)	.9210 (55)	.9855 (75)	.9202 (60)	.0653	7.10	
52	.9160 (1)	1.0407 (73)	.9680 (3)	.9517 (53)	1.0391 (74)	.9526 (56)	.0865	9.08	
53	1.1298 (2)	1.0646 (74)	1.0410 (1)	1.0540 (62)	1.0664 (76)	1.0537 (63)	.0127	1.21	4.18
54	1.0864 (3)	1.1074 (66)	1.0483 (3)	1.0837 (65)	1.1065 (69)	1.0821 (68)	.0244	2.25	
55	1.0300 (3)	1.1765 (71)	1.1346 (2)	1.1145 (46)	1.1705 (74)	1.1153 (48)	.0552	4.95	
56	...	1.1954 (37)	...	1.1486 (56)	1.1954 (37)	1.1486 (56)	.0468	4.07	3.59
57	1.2906 (4)	1.2315 (39)	1.2218 (3)	1.2155 (54)	1.2370 (43)	1.2158 (57)	.0212	1.74	
58	1.1651 (1)	1.2217 (16)	...	1.2502 (64)	1.2184 (17)	1.2502 (64)	−.0318	−2.54	
59	...	1.3128 (20)	...	1.2885 (35)	1.3128 (20)	1.2885 (35)	.0243	1.89	
60	...	1.3080 (12)	1.4636 (1)	1.3025 (29)	1.3080 (12)	1.3079 (30)	.0001	0.01	
61	...	1.4193 (7)	...	1.3281 (31)	1.4193 (7)	1.3281 (31)	.0912	6.87	
62	...	1.6551 (3)	...	1.4007 (29)	1.6551 (3)	1.4007 (29)	.2544	18.16	
63	1.5098 (1)	1.4881 (3)	...	1.4068 (19)	1.4936 (4)	1.4068 (19)	.0868	6.17	
64	...	1.5113 (4)	...	1.4550 (16)	1.5113 (4)	1.4550 (16)	.0563	3.87	
65	...	1.4707 (4)	...	1.4763 (10)	1.4707 (4)	1.4763 (10)	−.0056	−0.38	
66	...	1.7833 (2)	...	1.5725 (14)	1.7833 (2)	1.5725 (14)	...	...	
67	...	1.0998 (1)	...	1.6665 (6)	1.0998 (1)	1.6665 (6)	...	...	
68	...	1.6797 (2)	...	1.5924 (11)	1.6797 (2)	1.5924 (11)	...	...	
69	...	...	...	1.5287 (2)	...	1.5287 (2)	...	...	
70	...	...	...	1.5359 (4)	...	1.5359(4)	...	...	
71	...	...	...	1.4715 (2)	...	1.4715 (2)	...	...	
72	...	...	...	...	...	...	...	...	
73	...	...	...	1.5588(1)	...	1.5588 (1)	...	...	
74	...	...	...	2.0632 (1)	...	2.0632 (1)	...	...	

TABLE IX.—Haddock otolith weights as a percentage of the gutted and gilled weight of the fish in haddock of the southern Grand Bank, January to June, 1947–1950. (Slightly greater numbers of fish in the totals are caused by including in the totals some haddock of doubtful maturity and/or sex. Numbers in parentheses are numbers of fish.)

| Length of fish | Average of ratios of weight of two otoliths to gutted-and-gilled-weight of the fish, as percentage | | | | | | |
	Male, immature	Male, mature	Female, immature	Female, mature	Total males	Total females	Overall total
cm.	%	%	%	%	%	%	%
15	...	...	...	...			.307 (1)
16	.324 (1)	...	.312 (3)	...	.324 (1)	.312 (3)	.302 (5)
17	.224 (1)	...	.347 (1)		.224 (1)	.347 (1)	.280 (3)
18	.260 (2)	...			.260 (2)		.249 (3)
19	.275 (1)	...	.255 (1)		.275 (1)	.255 (1)	.265 (2)
20	...	...	...	...	...	...	...
21	...	...	...	...	...	...	...
22	...	...	...	...	...	...	...
23		...	...	...		...	...
24	.233 (1)	...	.273 (1)	...	.233 (1)	.273 (1)	.253 (2)
25	.199 (1)		.230 (1)		.199 (1)	.230 (1)	.215 (2)
26			.202 (1)			.202 (1)	.202 (1)
27	.183 (2)		.188 (1)		.183 (2)	.188 (1)	.185 (3)
28		...	...	...			
29	.184 (1)	...		...	.184 (1)		.184 (1)
30	.177 (2)	...	.172 (3)	...	.177 (2)	.172 (3)	.174 (5)
31	.163 (6)	...	.165 (3)	...	.163 (6)	.165 (3)	.164 (9)
32	.152 (3)	...	.157 (6)	...	.152 (3)	.157 (6)	.157 (10)
33	.157 (4)		.143 (7)	...	.157 (4)	.143 (7)	.148 (11)
34	.148 (8)	.148 (1)	.144 (7)		.148 (9)	.144 (7)	.146 (16)
35	.143 (16)	.148 (1)	.145 (13)	...	.143 (17)	.145 (13)	.144 (30)
36	.142 (9)	.145 (4)	.143 (15)	...	.143 (13)	.143 (15)	.143 (28)
37	.137 (22)	.115 (4)	.130 (23)	...	.134 (26)	.130 (23)	.132 (50)
38	.130 (20)	.135 (7)	.123 (25)	...	.131 (28)	.123 (25)	.127 (53)
39	.124 (22)	.123 (11)	.124 (22)	...	.124 (34)	.124 (22)	.124 (56)
40	.124 (13)	.129 (7)	.121 (25)	.148 (1)	.126 (20)	.122 (26)	.124 (47)
41	.107 (6)	.118 (16)	.117 (15)	.128 (1)	.115 (23)	.118 (16)	.116 (40)
42	.116 (18)	.114 (18)	.114 (24)	.120 (6)	.115 (36)	.115 (30)	.115 (66)
43	.116 (4)	.112 (29)	.113 (19)	.112 (11)	.112 (33)	.113 (30)	.112 (63)
44	.112 (2)	.106 (27)	.105 (13)	.107 (16)	.107 (29)	.106 (29)	.106 (58)
45	.102 (6)	.104 (36)	.097 (16)	.105 (16)	.104 (43)	.101 (32)	.103 (75)
46	.124 (1)	.102 (39)	.105 (7)	.098 (23)	.102 (40)	.100 (30)	.101 (70)
47	.100 (3)	.099 (36)	.098 (11)	.095 (30)	.099 (39)	.096 (41)	.098 (80)
48	...	.101 (39)	.096 (6)	.097 (30)	.101 (39)	.097 (36)	.099 (75)
49	...	.096 (34)	.092 (7)	.096 (24)	.096 (34)	.095 (31)	.096 (65)
50	...	.098 (25)	.088 (2)	.090 (25)	.098 (25)	.090 (27)	.094 (52)
51	...	.097 (29)	.092 (3)	.092 (20)	.097 (29)	.092 (24)	.095 (53)
52	.075 (1)	.093 (28)	.084 (1)	.089 (20)	.093 (29)	.089 (21)	.091 (51)
53	...	.092 (32)	...	.095 (21)	.092 (32)	.095 (21)	.093 (53)
54	.095 (1)	.091 (26)	.080 (1)	.089 (20)	.091 (27)	.089 (21)	.090 (48)
55	.078 (1)	.094 (27)	...	.088 (16)	.093 (28)	.087 (17)	.091 (45)
56	...	.089 (11)	...	.087 (22)	.088 (12)	.087 (22)	.087 (34)
57	.106 (1)	.091 (11)	...	.091 (25)	.092 (12)	.091 (25)	.091 (37)
58	...	.087 (4)	...	.084 (31)	.087 (4)	.084 (31)	.084 (35)
59	...	.079 (9)	...	.085 (15)	.079 (9)	.085 (15)	.082 (24)
60	...	.079 (7)	...	.081 (13)	.079 (7)	.081 (13)	.080 (20)
61	...	.082 (4)	...	.082 (11)	.082 (4)	.082 (11)	.082 (15)
62	...	.070 (2)	...	.069 (11)	.070 (2)	.069 (11)	.069 (13)
63	...	...	...	.086 (6)	.070 (1)	.086 (6)	.085 (8)
64	...	.069 (1)	...	.072 (9)	.069 (1)	.072 (9)	.072 (10)
65	...	...	...	.071 (3)		.071 (3)	.071 (3)
66	...	.065 (1)	...	.066 (3)	.065 (1)	.066 (3)	.066 (4)
67	..	.038 (1)	...	.067 (4)	.038 (1)	.067 (4)	.062 (5)
68	...	...	...	.083 (4)		.083 (4)	.083 (4)
69	...	...	...				
70	...	...	...	.059 (3)		.059 (3)	.059 (3)
71	...	...	...	.050 (2)		.050 (2)	.050 (2)
74	...	...	...	.065 (1)		.065 (1)	.065 (1)

haddock populations is the otolith weight as a percentage of the weight of the fish.

A study has been made of otolith weight relative to the gutted and gilled weight of immature and mature male and female haddock taken from January to June, 1947 to 1950, on the southern part of the Grand Bank (Table IX). The fish weights were taken on shore from landings of iced round fish. Only fish in good condition were weighed.

The distinct differences occurring between the actual otolith weights of immature and mature male, immature and mature female and of male and female fish of the same length as seen in Table VIII and Figure 7, are not to be found when otolith weights are expressed as a percentage of fish weight.

Also, with increasing fish size considerable reduction occurs in otolith weight as a percentage of the fish weight, from approximately 0.3% at 15–16 cm. to about 0.06% at 70–74 cm. (Table IX).

DISCUSSION. We have shown that on the Grand Bank and St. Pierre Bank, in haddock of the same length, the slow-growing fish possessed heavier otoliths than fast-growing fish.

The literature on fishes is replete with examples of male fish maturing at an earlier age and smaller size than the female. It is usual in these cases for the rate of growth of the male to show a decrease compared with that of the female. For example, Hansen (1949) for the cod in Greenland waters shows that beyond the fifth year of age the female cod become increasingly larger than the males.

Our age and growth studies have not yet reached the point where a good comparison of the growth of male and female haddock can be made, and we have not found in the literature a comparison of the growth of male with that of female haddock.

In our samples, however, the smallest maturing male fish were 34 cm. while the smallest maturing females were 40 cm. in length (Table VIII). Approximately 50% of the male fish were mature or maturing at 41 cm. while it was not until a length of 44 cm. was attained that 50% of the females were mature. Over 90% of the male fish were mature or maturing at 46 cm. but it was only at 51 cm. that 90% of the females attained a mature or maturing condition.

While the matter cannot be discussed in detail here, male haddock in the Grand Bank area become sexually mature at least a year younger than females.

It will be noted also from Table VIII that the males did not grow to as great a length as the females. Most of the larger fish were females while the mature male fish, apparently in fewer length categories because of slower growth, were more numerous than the females at intermediate lengths.

It is, therefore, most probable that the superiority in weight of the otoliths of the larger male haddock over that of otoliths from females of the same length is due to the slower growth of the male fish after they have become sexually mature.

It is also evident from our studies of haddock age and growth that, in fish of the same length, the mature male and female haddock are on the average

older and slower growing than immature fish of the same sex and thus possess heavier otoliths.

In male fish of 47 cm. or more in length and in females of 52 cm. or more, the superiority in weight of otoliths of the mature fish over that of the immature became irregular or absent (Table VIII). This can be attributed partly to variability due to the small numbers of immature fish at these sizes, but also at the larger sizes there are doubtless some errors in calling fish immature. Fish which have gone more than one year between spawnings, or young fish which have spawned once and are passing through the immature condition between spawnings, may occasionally be called immature.

The apparent explanation of the lack of clear distinction between the otolith weights of immature and mature and of male and female haddock, when the otolith weights are expressed as a percentage of fish weight, is that both otolith and fish weight in slow-growing haddock are greater than in faster-growing haddock of the same length in the same area. Thus, when otolith weight is expressed as a percentage of fish weight the differences in otolith weight between fast- and slow-growing fish tend to cancel out.

CONCLUSIONS ON THE USE OF OTOLITH LENGTH AND WEIGHT MEASUREMENTS FOR POPULATION DIFFERENTIATION

The otolith-length and otolith-weight differences shown in this paper in haddock of the same length but of different ages indicate that both measurements and weights of otoliths may be useful in differentiating between fish populations.

Older haddock have heavier and longer otoliths than younger fish of the same length. Thus the usefulness of the two methods of otolith measurement, for population differentiation, depends on the populations having different growth rates. Differing numbers of fish in a year-class relative to other year-classes will also produce differences in the relation of otolith weight or length to the length of the fish. These differences are caused by the fast-growing fish in the upper part of the frequency and the slow-growing fish in the lower part of the frequency of a very numerous year-class dominating the curve at the appropriate points. On another bank with a similar growth rate but differing year-class strengths these portions of the curve may be dominated by fish of a different year-class.

Thus it is that from differences in growth-rate and differences in year-class strengths between areas, there are very likely to be differences in the relation of otolith length or weight to length of the fish, which will be useful for differentiating between populations.

The shape of the otolith–fish-length curves on a particular bank is certain to be flexible and will vary from year to year as variations in fish growth rate and in year-class strength occur. While in the data presented in this paper for haddock the otolith weight and otolith length appear to be equally suitable for distinguishing between populations, it is our opinion that the otolith weight, which takes account of all proportions of the otolith, is likely to be the more generally useful criterion. In the cod, *Gadus callarias* (L.), we have found

otolith weights much more useful than otolith lengths in differentiating between populations.

If differences between the otolith-length or -weight, fish-length curves between banks are small and if the samples are sufficiently large it will be worthwhile to separate male and female fish in the comparisons.

Otolith weight–fish weight relationships are unlikely to be of much value in differentiating populations since both otolith and fish weights may vary in the same direction.

ACKNOWLEDGMENTS

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Parasitic Helminths and Arthropods from Pinnipedia of the Canadian Pacific Coast[1]

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ABSTRACT

From *Phoca vitulina richardi* the following parasites are recorded: *Corynosoma strumosum* (Acanthocephala); *Terranova decipiens* and *Contracaecum osculatum* (Nematoda); *Halarachne* sp. (Acarina); *Echinophthirius horridus* (Anoplura). From *Eumetopias jubata* are recorded *Diphyllobothrium pacificum*, *Diplogonoporus tetrapterus* and *Abothrium gadi* (Cestoda); *T. decipiens*, *C. osculatum* and *Parafilaroides* sp. (Nematoda); *Corynosoma villosum* (Acanthocephala); *Orthohalarachne diminuata* (Acarina): *Antarctophthirus microchir* (Anoplura). *E. jubata* is probably not a true host of *A. gadi*, the parasite apparently being introduced by ingestion of infected fishes of the family Gadidae, the normal definitive hosts. Notes on host and geographical distribution, nomenclature and morphology of the parasites are included. *Diphyllobothrium pacificum* is a new combination for *Adenocephalus pacificus*. *E. jubata* is a new host record for *D. pacificum*, *D. tetrapterus* and *O. diminuata*. Several new geographical records are reported. The occurrence of larval stages of *T. decipiens* and *C. strumosum* in fishes is noted.

INTRODUCTION

Two species of Pinnipedia inhabit the Pacific waters of Canada the year round. These are *Phoca vitulina richardi·* (fam. Phocidae), the North American Pacific sub-species of the common harbour seal, and *Eumetopias jubata* (fam. Otariidae), the Steller sea lion.

These two pinniped species were examined as part of a survey undertaken to discover the definitive hosts of the *Anisakis* larvae (Nematoda) found in British Columbia marine fishes. Advantage was taken of the opportunity to examine the available pinnipeds for all parasites. The results of the studies on the collections made are presented here. Where necessary descriptions and discussions on the relationship of the parasites are given. Notes on nomenclature, and host and geographical distribution are also presented.

The animals examined were obtained from two main sources. Twelve *P.v. richardi* (10 adults and 2 pups) were shot near the mouth of the Skeena River about June 25, 1953. The seals subsequently were frozen and brought to the Biological Station at Nanaimo, where they were thawed and examined. Two other *P.v. richardi*, one from the mouth of the Fraser River and one from Knight Inlet were caught in fishermen's nets during September, 1951. These animals were examined in the fresh state. Most of the *E. jubata* material was collected from freshly killed animals at Triangle Island (the outermost of the Cape Scott Islands that extend westward from the northern tip of Vancouver Island), during the breeding season between June 12 and June 20, 1953. Fifteen adults and two pups

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were examined, but with the exception of the stomach not all organs of each animal were searched for parasites. Further *E. jubata* material was examined from the collections of the Institute of Parasitology, McGill University.

CESTODA

Family DIPHYLLOBOTHRIIDAE Lühe, 1910

Genus *Diphyllobothrium* Cobbold, 1858

Diphyllobothrium pacificum (Nybelin, 1931) comb. nov. (Fig. 16–18)

Bothriocephalus sp. Stiles and Hassall, 1899;
Adenocephalus pacificus Nybelin, 1931;
Adenocephalus septentrionalis Nybelin, 1931;
"Species No. 2" Stunkard, 1948;
Diphyllobothrium glaciale Markowski, 1952.

Two complete worms and several fragments (one of which included the scolex) of this species were obtained from Professor T. W. M. Cameron of the
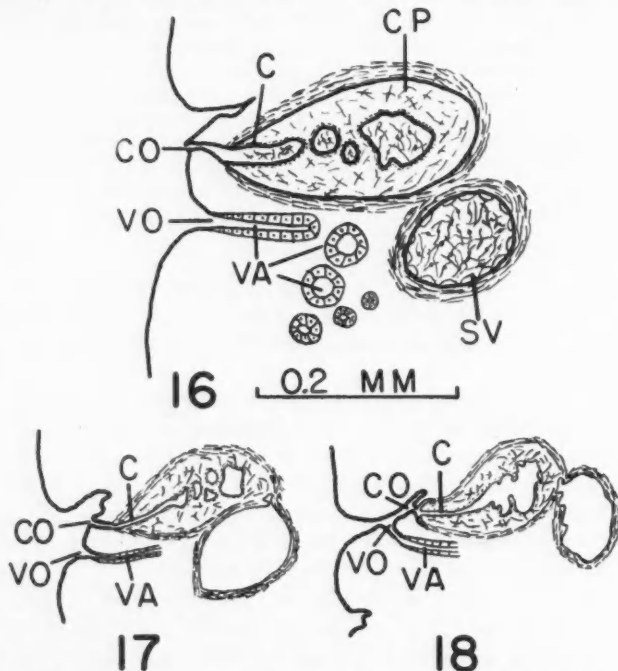
FIG. 16–18.—*Diphyllobothrium pacificum* (scale applies only to Fig. 16).
16. Sagittal section through genital atrium, vagina and cirrus pouch of specimen from *E. jubata*. Mag. about 175 ×.
17. Same of specimens from *A. phillipi* (after Nybelin, 1931). Mag. about 105 ×.
18. Same of specimens from *C. ursinus* (after Nybelin, 1931). Mag. about 115 ×.
C = cirrus; CO = cirrus opening; CP = cirrus pouch; SV = external seminal vesicle; VA = vagina; VO = vaginal opening.

Institute of Parasitology. According to the accompanying label the material was collected from the large intestine of a "sea lion" caught in Quatsino Sound, Vancouver Island, British Columbia on November 27, 1937. Because of the locality of capture, "sea lion" almost certainly refers to *Eumetopias jubata*.

A description of the present material of *D. pacificum* need not be presented as the descriptions and illustrations of Nybelin (1931), Stunkard (1948), Yamaguti (1951a) and Markowski (1952b) are fully adequate.

Markowski (1952b) gave the most recent account of the species under the name *Diphyllobothrium glaciale*. He considered the following species as synonyms: *Bothriocephalus* sp. Stiles and Hassall, 1899; *Clestobothrium glaciale* Cholodkovsky, 1915; *Adenocephalus pacificus* Nybelin, 1931; *Adenocephalus septentrionalis* Nybelin, 1931 and "Species No. 2" of Stunkard, 1948. *Bothriocephalus* sp., *C. glaciale*, *A. septentrionalis* and "Species No. 2" were described from material taken from *Callorhinus ursinus* of the North Pacific, the description of *A. septentrionalis* being based entirely on some of the original specimens of *Bothriocephalus* sp. Stunkard's description of "Species No. 2" was based mainly on a new collection of cestodes from *C. ursinus* but he stated that he also examined the specimens of Stiles and Hassall's *Bothriocephalus* sp. (deposited in the U.S. National Museum) and found them to be identical with his new material. *Adenocephalus pacificus* was first described by Nybelin (1931) from *Arctocephalus australis*[2] of the Juan Fernandez Islands of the Southeast Pacific and later by Yamaguti (1951a) from *C. ursinus* of the North Pacific. Markowski's (1952b) description of *D. glaciale* was based entirely on specimens of Nybelin's *A. septentrionalis* (i.e. the original *Bothriocephalus* sp. of Stiles and Hassall) but he also had at his disposal specimens of Nybelin's *A. pacificus*.

In agreement with Markowski, I consider *Bothriocephalus* sp. Stiles and Hassall, *A. pacificus*, *A. septentrionalis* and "Species No. 2" of Stunkard conspecific. However, on present evidence, I do not feel it is justified to place this group in synonymy with *Clestobothrium glaciale*, as suggested by Markowski. Cholodkovsky's (1915) description states, and his illustration indicates, that the genital cloaca (cirro-vaginal opening) occurs on the dorsal surface and the uterine pore occurs on the ventral surface of the segments, whereas in the present species both pores open on the ventral surface of the segments.

Subscribing to Markowski's (1952b) suppression of *Adenocephalus* as a synonym of *Diphyllobothrium*, the tapeworm under consideration becomes *Diphyllobothrium pacificum* (Nybelin, 1931) comb. nov. (*A. pacificum* Nybelin having page priority over *A. septentrionalis* Nybelin). The generic name *Bothriocephalus* is not applicable to this species.

[2]Markowski (1952b) treated *A. australis* as a synonym of *Neophoca cinerea*. Sivertsen (1954) pointed out that these two pinnipeds are distinct species, the former being a fur seal occurring on the southeastern coast of South America and the latter a sea lion occurring only in Australian–New Zealand waters. He further indicated that the fur seal of the Juan Fernandez Islands is a distinct species, *Arctophoca philippi*, which is probably the host of Nybelin's *A. pacificus*.

Wardle, McLeod and Stewart (1947) examined cestodes, which are apparently *D. pacificum*, from *C. ursinus* from Alaska and considered them identical with *Diphyllobothrium arctocephalinum* Johnston, 1937. They removed this species to their new genus, *Cordicephalus*. Neither Stunkard (1948) nor Markowski (1952b) accepted *Cordicephalus* as a valid genus and Markowski (1952b) placed *D. arctocephalinus* Johnston in synonymy with *D. scoticum* (Rennie and Reid, 1912), a cestode restricted to pinnipeds of the southern hemisphere.

In the descriptions of *D. pacificum* (under its various synonyms) one major discrepancy occurs. Nybelin (1931) and Markowski (1952b) described a common cirro-vaginal atrium and illustrated this from sagittal sections.[3] Stunkard (1948) and Yamaguti (1951a) described the vaginal pore opening to the exterior separately and behind the male pore, but did not illustrate sagittal sections. In ventral mounts of whole proglottids, as illustrated by Stunkard and Yamaguti, as well as Nybelin the two pores appear to open separately. My experience with *D. pacificum* from *E. jubata* leads me to believe that the true relationship of the male and female pores is only revealed by examination of sagittal sections. Ventral whole mounts of my specimens suggest that the male and female pores open independently on the surface of the proglottid but study of median sagittal sections demonstrates that they open into a very shallow common genital atrium, the vagina opening posterior to the cirrus at the posterior margin of the genital atrium. Figure 16 illustrates a median sagittal section through the genital atrium, vagina and cirrus pouch of *D. pacificum* from *E. jubata*. Figures 17 and 18 are reproductions of similar sections of Nybelin's "*A. pacificus*" and "*A. septentrionalis*" copied from Nybelin (1931), page 498, text figures 5 and 6 and have been included here for comparative purposes. The differences in shape and depth of the genital atrium as seen in Figs. 16 to 18 are probably attributable to different degrees of muscular contraction of the proglottids. I believe that if sagittal sections of Stunkard's and Yamaguti's specimens were re-examined at least a shallow common genital atrium would be found.

The present record from *E. jubata* adds a third host to those previously cited for *D. pacificum*, which is best known from the fur seal (*C. ursinus*) of the North Pacific but has also been found in the fur seal (*A. philippi*) of the Juan Fernandez Islands.

Genus *Diplogonoporus* Lönnberg, 1892
Diplogonoporus tetrapterus (von Siebold, 1848) Ariola, 1896. (Fig. 1–5)

A complete gravid worm was contained in the same vial as the previous species. The host and locality are therefore identical for the two species.

Although certain differences from Markowski's (1952b) redescription of the type-material of *D. tetrapterus* were noted the present specimen is assigned to this species in the light of recent work by Markowski (1952a, 1952b) and Rausch (1954) on morphological variation in diphyllobothriids.

[3]Nybelin's figures of "*A. pacificus*" and "*A. septentrionalis*" indicate that the genital atrium in the former is shallow and broad, whereas that in the latter is deep and narrow. The shape of the atrium probably is greatly affected by the state of muscular contraction of the proglottid.
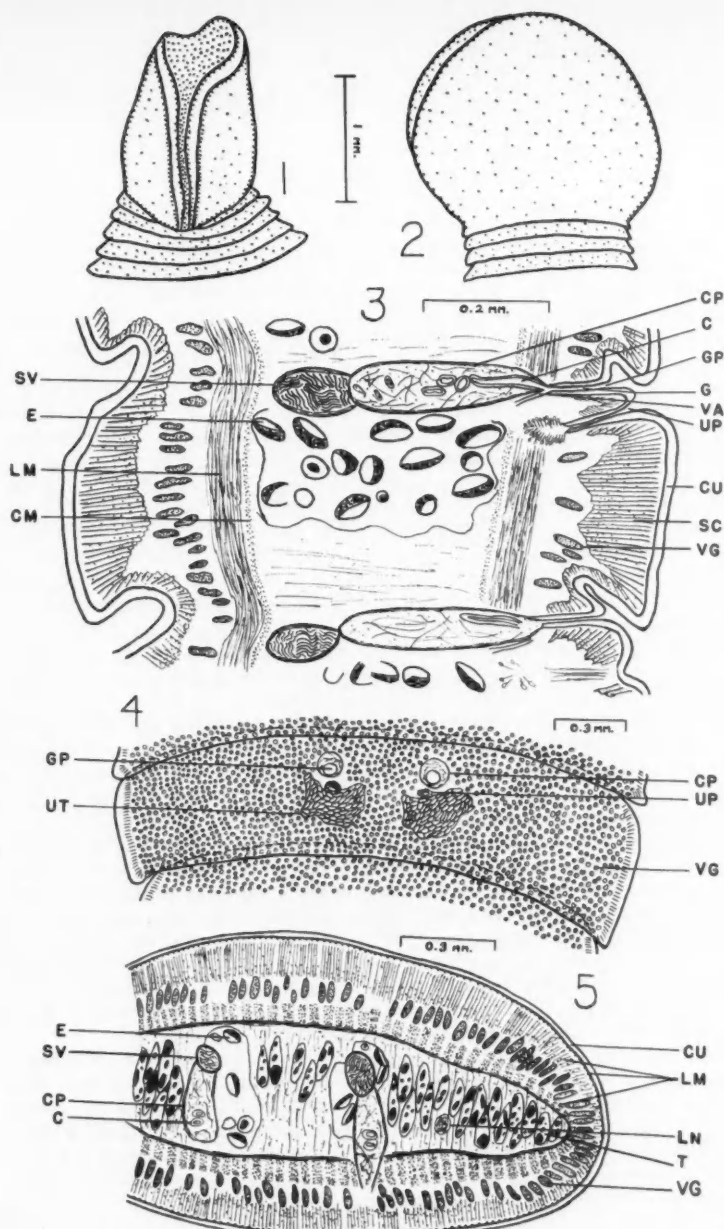
FIG. 1–5.—*Diplogonoporus tetrapterus*

1. Scolex, surficial view.
2. Scolex, lateral view.
3. Sagittal section of gravid proglottids in region of cirrus pouch.
4. Ventral view of gravid proglottid.
5. Transverse section of gravid proglottids in region of cirrus pouches.

C =cirrus; CP = cirrus pouch; CM = circular muscles; CU = cuticle; E = egg; G = genital atrium; GP = genital pore; LM = longitudinal muscles; LN = longitudinal nerve cord; SC = subcuticula; SV = seminal vesicle; T = testes; UP = uterine pore; UT = uterus; VA = vagina; VG = vitelline gland.

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DESCRIPTION: The entire worm measures 120 mm. in length and consists of a scolex and about 435 proglottids. A neck is lacking, the scolex slightly overlapping the first segment.

The scolex is oval in surficial view and nearly circular in lateral view, 1.54 mm. long, 1.19 mm. wide and 1.70 mm. deep. The bothria extend the complete length of the scolex and are widest anteriorly.

The segments are craspedote and the lateral margins serrate. Secondary divisions of the primary segments, as described by Stunkard (1948) for his "Species No. 3" is apparent. The genital rudiments appear first in about segment 170 and eggs are visible in the last 30 proglottids. The genitalia are double in all segments in which they are apparent. The terminal segment measures 0.83 mm. in length by 1.9 mm. in width. Other gravid segments measure about 0.46–0.62 mm. long by 2.1–2.5 mm. wide.

In transverse section of a gravid proglottid, 2.24 mm. wide and 0.91 mm. thick, the cuticula is 0.01 mm. thick. Beneath the cuticula there is a thin layer of circular muscle fibres and then a single layer of longitudinal fibres. The cortical zone, 0.168 mm. thick laterally and 0.280 mm. thick medially, consists of an outer cellular zone, 0.112 mm. thick, a vitelline zone, 0.105 mm. thick, a layer of longitudinal muscle fibres, 0.060 mm. thick and a layer of circular fibres, 0.010 mm. thick (all measurements of the layers of the cortical zone were taken medially). The cortical cellular zone contains scattered longitudinal fibres that are most concentrated internally. The medullary zone is 0.14 mm. thick laterally and 0.35 mm. thick medially.

The two main longitudinal nerves lie in the medullary zone, one on each side, about ⅓ the distance between the cirrus pouch and the lateral margin of the proglottid. In immature proglottids their diameter is about 0.070 mm.

The main longitudinal excretory canals are medullary and lie, one in each lateral zone, about midway between the cirrus pouch and the nerve cord or a little closer to the nerve cord. They measure 0.015 mm. in diameter in immature segments.

The two common cirro-vaginal (genital) pores in each segment are ventral, submedian, lie close to the anterior margin of the proglottid and are separated by a distance ⅕–¼ the width of the proglottid. In a proglottid 2.1 mm. wide they are 0.49 mm. apart. The vagina opens into the common genital atrium immediately posterior to the male pore. The uterine pores are situated a short distance posterior to the genital pores.

In young segments the testes are circular, or slightly oval in transverse section. In gravid proglottids they are arranged in 2 or 3 irregularly alternating layers and are elongate-oval in transverse and sagittal sections, the maximum dimension occurring in the dorso-ventral axis. They measure 0.088–0.140 mm. dorso-ventrally, 0.018–0.038 mm. in antero-posterior diameter and 0.035–0.069 mm. in latero-lateral diameter. They occupy most of the lateral area of the medulla and are continuous in the anterior, dorsal portion of the medulla of gravid proglottids; they form a continuous sheet from segment to segment. There are 25–40 follicles (10–17 in each lateral zone and 5–7 between the cirrus pouches) in transverse sections of a gravid proglottid and 10–18 follicles in sagittal sections.

Each cirrus pouch lies in the anterior portion of the segment, one on either side of the midline and is directed dorso-ventrally. It is elongate-oval, 0.301–0.332 mm. in length, 0.088–0.123 mm. diameter in sagittal section and 0.123–0.133 mm. diameter in transverse section. The cirrus, when retracted, is coiled in the dorsal portion and straight in the ventral portion of the cirrus sac. The straight portion of the cirrus leads into the genital atrium. An external seminal vesicle or "Propulsionsblase", 0.140–0.161 mm. dorso-ventrally by 0.098–0.119 mm. antero-posteriorly by 0.119–0.133 mm. latero-laterally, lies dorsal to the cirrus pouch. The muscular wall of the "Propulsionsblase" is continuous with, but thicker than, the muscular wall of the cirrus pouch.

The bilobed ovaries lie in the submedian, ventral, posterior region of the segment, the two ovaries of each segment almost touching medially. Mehlis' gland lies posteriad and dorsad to the ovary. The uterus cannot be traced in gravid segments, but is coiled between the ovary and the uterine pore and partially surrounds the cirrus pouch and "Propulsionsblase". The two uteri of a segment are not in contact with one another. The ova measure 0.063–0.071 mm. in length by 0.036–0.045 mm. in diameter.

The vitellaria consist of a layer of numerous follicles in the cortical zone, external to the main longitudinal musculature. The follicles are continuous from segment to segment and are continuous around each segment except for a more or less brief interruption, dorsally and ventrally, in the ovarian and uterian regions. They are present between the two sets of genitalia in each proglottid. The vitelline follicles are elongate-oval in transverse and sagittal sections. They measure 0.045–0.087 mm. dorso-ventrally, 0.017–0.038 mm. in diameter.

DISCUSSION: The specimen described above differs from Markowski's description of *D. tetrapterus* from *Phoca vitulina* in the absence of a neck, the presence of a larger scolex, larger eggs, larger external seminal vesicle, shorter gravid segments, more oval testes and vitellaria, greater number of testes in transverse section of gravid proglottids and in the size and shape of the cirrus sac. However, these differences do not seem to be of a specific nature. Some of them can be attributed to different states of muscular contraction, while others seem to be due to normal morphological variation of diphyllobothriid species, possibly in part the result of growth and development in different hosts and differences in age. Recently, Rausch (1954) has shown that there is extreme morphological variation in such characters as mentioned above in *Diphyllobothrium ursi* from bears in Alaska. He attributed some of these variations to differences in age, effects of crowding and effects of different states of muscular contraction. Other characters were described as having a wide normal variation for the species.

Stunkard's (1948) "Species No. 3" from *Callorhinus ursinus* from Alaska is remarkably similar to the specimen herein described, the only real difference occurring in the relation of the genital pores. In the present specimen the uterine pore opens to the exterior behind the opening of the common cirro-vaginal atrium, whereas Stunkard describes a common atrium into which open the male and female ducts and the uterus, with the result that there is only one pore opening to the exterior.

The absence of cestodes from the fresh sea lions examined at Triangle Island is possibly due to a seasonal variation in infection. The cestode-infected sea lion was taken in November, whereas the non-infected individuals were taken from the rookeries in June, when feeding is at a minimum.

<div align="center">

Family AMPHICOTYLIDAE Nybelin, 1922

Genus *Abothrium* Beneden, 1871

Abothrium gadi Beneden, 1871

</div>

Many fragmented and some complete strobilae were present in material obtained from Professor T. W. M. Cameron. The label indicated that these specimens were collected from the small intestine of a female *E. jubata* at Quatsino Sound on November 27, 1937. This host is probably the same animal from which *D. pacificum* and *D. tetrapterus* were obtained.

Abothrium gadi is a well-known parasite of marine gadids and has frequently been observed by the author in the intestine of *Gadus macrocephalus* and *Theragra chalcogramma* caught in British Columbia waters. Its presence in *E. jubata* probably is indicative of recent ingestion of infected gadids.

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NEMATODA

Family METASTRONGYLIDAE Leiper, 1909
Sub-family FILAROIDINAE Skrjabin, 1933
Genus *Parafilaroides* Dougherty, 1946
Parafilaroides sp. (spp.?)

Many specimens of this genus were collected from the parenchyma of the lungs of one *E. jubata*. The worms, *in situ*, resemble small irregularly coiled or folded white threads and are readily visible to the naked eye.

Unfortunately, laboratory examination of the material revealed that, apparently because of their delicate structure, the worms did not satisfactorily withstand fixation in hot 70 per cent alcohol. Most of the worms fragmented and some of the details of internal anatomy are obscured, even in the entire worms.

As pointed out by Dougherty and Herman (1947), members of this genus, because of their degenerate nature, lack good morphological criteria for separation of species. The species have been distinguished mainly on the body size and other measurements. The females in the present collection show a greater variation in measurements, other than total body length, than indicated for known species (cf. Dougherty and Herman, 1947; Mawson, 1953) and hence possibly comprise more than one species. I hesitate to make a decision on this point, because of the paucity of complete worms. Descriptions and naming of the present form(s) must await collection of further material.

Family ANISAKIDAE Skrjabin and Karokhin, 1945
Genus *Terranova* Leiper and Atkinson, 1914

The genus *Terranova* was established by Leiper and Atkinson (1914) for *T. antarctica* from a shark from New Zealand. This species lacked interlabia. Baylis (1920) considered *Terranova* a synonym of *Porrocaecum* Railliet and Henry, 1912, of which the type species is *P. crassum* (possessing interlabia) from a bird. Subsequent authors accepted this synonymy. Johnston and Mawson (1945) pointed out that apparently there are two natural groups of species in *Porrocaecum*. One group, found in birds, possesses interlabia and the other group, found in elasmobranchs, fishes and marine mammals, lacks interlabia. For the latter group they resurrected the genus *Terranova*, and retained *Porrocaecum* for the group with interlabia. *Porrocaecum decipiens*, lacking interlabia, was transferred to *Terranova*.

Terranova decipiens (Krabbe, 1878) Johnston and Mawson, 1945. (Fig. 6–14)

This nematode was found in the stomachs of 15 adult *Eumetopias jubata* examined at Triangle Island and in 9 out of 10 adult *Phoca vitulina richardi* examined from the mouth of the Skeena River. Up to 60 specimens were found in a single *P.v. richardi* and as many as 200 in an *E. jubata*.

The literature recording the occurrence of *T. decipiens* is extensive (cf. Stiles and Hassall, 1899; Baylis, 1937; Johnston and Mawson, 1945; Dollfus, 1953) and indicates that it is universally distributed and probably parasitizes all species
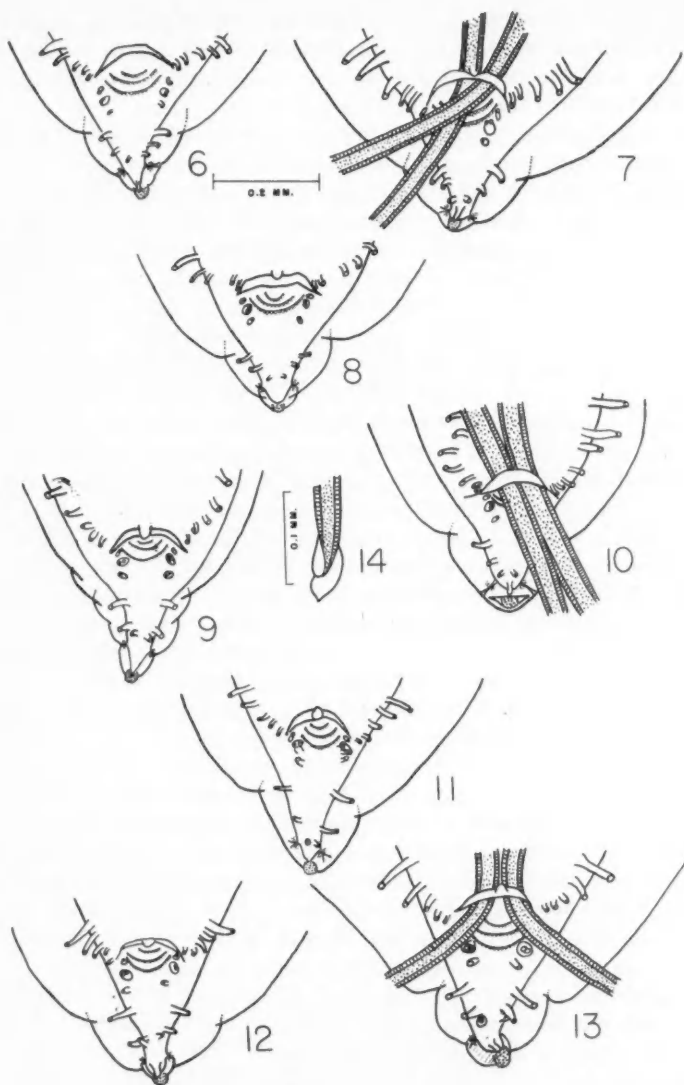
FIG. 6–14.—*Terranova decipiens*

6–13. Posterior extremity of male, ventral view; all drawn to same scale.
6–8. From undetermined seal, Atlantic coast of Canada; 9 and 10 from *Phoca vitulina richardi*, British Columbia; 11–13 from *Eumetopias jubata*, British Columbia.
14. Distal tip of spicule.

of Pinnipedia. It has been recorded several times from the Pacific coast of North America from the two host species examined in this survey, as well as in others (Stiles and Hassall, 1899; Scheffer and Sperry, 1931; Scheffer and Slipp, 1944; Fisher, 1952; Rausch, 1953; Schiller, 1954).

Although it seems unnecessary to fully describe this species, comments on the structure of the caudal end of the male would be of value.

The tail of the male (Figs. 6–13), that is the region between the cloaca and the posterior extremity, is conical, measures 0.25–0.30 mm. in length and terminally bears a small, spined, conical process. There are three caudal alae; one is continuous around the tip of the tail, two are lateral and extend somewhat anterior to the cloaca. These alae are muscular rather than composed solely of cuticula. The width of the lateral alae varies considerably (see Figs. 6–13). Just posterior to the cloaca there are three arcuate dentate ridges. There are about 55–100 pre-cloacal predunculate papillae on either side and 6 pairs of post-cloacal pedunculate papillae of which 3 are near the cloaca and in line with the pre-cloacal papillae. Of the anterior group of post-cloacal papillae the middle pair is the largest and has double endings. The first pair lie lateral to the dentigerous ridges, the third pair postero-lateral thereto and the second pair are usually lateral to, but sometimes postero-lateral to the dentigerous ridges. Of the posterior 3 pairs of papillae 2 pairs are sub-lateral and the most posterior pair lies close to the mid line. They decrease in size posteriorly. The distance between the posterior papillae is variable, but in the specimens examined papillae 5 and 6 are usually closer than 4 and 5. A pair of phasmids are present immediately behind and lateral to the sixth pair of post-cloacal papillae. Yamaguti and Arima (1942) and Yamaguti (1951b) in establishing *Porrocaecum azarasi* and *Porrocaecum callotariae*, apparently described the phasmids as a seventh pair of post-cloacal papillae. A median, sub-terminal, papilliform structure is present. The ease with which the sub-terminal papilliform structure and the terminal spined process are observed, or their prominence, apparently depends largely on the state of contraction or ventral curvature of the posterior tip of the tail and the angle from which it is viewed. A second median papilliform protuberance may occur on the anterior margin of the cloaca. The median sub-terminal and pre-cloacal papillae differ in structure from the sub-median or paired caudal papillae. The spicules are 'equal in length, measuring 1.5–2.5 mm.

The specimens from *P.v. richardi* and *E. jubata* from British Columbia were compared with specimens collected from seals from the Atlantic coast of Canada and from the bearded seal (*Erignathus barbatus*) from St. Lawrence Island, Alaska, and appeared not to differ. The Atlantic specimens were obtained from the Fisheries Research Board of Canada Biological Station, St. Andrews, N.B., through the kindness of the Director, Dr. J. L. Hart, and the Alaskan specimens were collected by Mr. F. H. Fay of the University of British Columbia.

Porrocaecum azarasi Yamaguti and Arima, 1942 described from *Histriophoca fasciatus* from Japan, and *Porrocaecum callotariae* Yamaguti, 1951 described from *Callotaria* (= *Callorhinus*) *ursinus* from the North Pacific, are probably synonyms of *Terranova decipiens*.

Fish serve as intermediate hosts in the life history of *T. decipiens*. The larvae are found encapsulated in the body musculature and consequently are of considerable economic importance when present in food-fishes. The process of encapsulation has been described by Kahl (1938). In British Columbia the fishes *Gadus macrocephalus*, *Anoplopoma fimbria*, *Ophiodon elongatus* and *Hippoglossus stenolepis* have been found to serve as intermediate hosts. In Alaska, Stiles and Hassall (1899) reported *T. decipiens* larvae from *G. macrocephalus* and *Theragra chalcogramma*, Scheffer and Slipp (1944) also found them in *G. macrocephalus* and Schiller (1954) collected them from *Lebius superciliosus* and *Hemilepidotus hemilepidotus*.

Genus *Contracaecum* Railliet and Henry, 1912
Contracaecum osculatum (Rudolphi, 1802) Baylis, 1920

This nematode was encountered, along with *T. decipiens*, in the stomachs of 9 out of 10 adult *P.v. richardi* from the Skeena River and in the stomachs of 15 *E. jubata* examined at Triangle Island. These two nematode species were the most common and abundant parasites encountered and the only parasites common to both host species investigated.

Contracaecum osculatum was previously collected from *P.v. richardi* in British Columbia by Fisher (1952). It has also been identified from other pinnipeds of the Northeast Pacific by Stiles and Hassall (1899), Caballero and Peregrina (1938) and Herman (1942).

This parasite is apparently cosmopolitan in distribution and is found in many species of pinnipeds (Baylis, 1937; Johnston and Mawson, 1945).

Contracaecum callotariae, described by Yamaguti (1951b) from *Callorhinus ursinus*, is considered a synonym of *C. osculatum*.

Fish are very likely the intermediate hosts of *C. osculatum*. In British Columbia at least 25 species of fish have been found to harbour larval *Contracaecum* encysted in the viscera. However, other species of *Contracaecum* occur in this region and it is impossible to determine, on morphological grounds, which larvae belong to *C. osculatum*.

ACANTHOCEPHALA

Family POLYMORPHIDAE Meyer, 1931
Genus *Corynosoma* Lühe, 1904
Corynosoma strumosum (Rudolphi, 1802)

The intestines of the 12 adult harbour seals examined were infected with from 1 to more than 300 individuals of this species. Fisher (1952) listed *C. semerme* (Forssell) as a parasite of a harbour seal caught near the Fraser River, but did not find *Corynosoma* in harbour seals from near the Skeena River. In a recent personal communication, Mr. Paul Montreuil of the Institute of Parasitology, after examining Fisher's material confirmed my earlier supposition (Margolis, 1954) that the latter's specimens were actually *C. strumosum*.

Records of the occurrence of *C. strumosum* in the harbour seal and other pinnipeds of the northeast Pacific have been summarized elsewhere (Margolis, 1954).

Several fish intermediate (or transport) hosts of this acanthocephalan have been found on the west coast of North America. In British Columbia (Departure Bay, Vancouver Island), Ekbaum (1938) found *Platichthys stellatus* and *Lepidopsetta bilineata* harboured *Gadus macrocephalus* from Puget Sound, and Ward and Winter (1952) recorded *Umbrina roncador* from California as hosts of this parasite. To this fish host list can be added *Psettichthys melanostictus*, the sand sole, a specimen of which was collected June 6, 1954 at the mouth of the Fraser River, British Columbia, infected with 14 visceral cysts of *C. strumosum*.

The most recent and detailed description of *C. strumosum* is to be found in Van Cleave's (1953) publication on the Acanthocephala of North American mammals. According to Van Cleave each of the 18 longitudinal rows of proboscis hooks consists of 10 or 11 hooks, of which the proximal 4 are simple and the anterior 5 or 6 (occasionally 7) possess backwardly directed roots. The present material indicates 10 to 12 hooks in each row, of which the posterior 4 or 5 are simple and the anterior 5 to 7 have backwardly directed roots. European parasitologists (Meyer, 1932; Wülker and Schuurmans-Stekhoven, 1933) had previously noted the number of hooks in each row on the proboscis as 10 to 12.

Corynosoma strumosum is apparently a widely distributed parasite of pinnipeds in the Northern Hemisphere, having been recorded from no less than eight species in Europe, Asia and North America. Van Cleave (1953) believes it is not present in pinnipeds of the Southern Hemisphere. A list of the pinniped and fish hosts, as well as accidental bird hosts is given by Lühe (1911), Meyer (1932), Dollfus (1953) and Van Cleave (1953).

Corynosoma villosum Van Cleave, 1953

The intestines of four *E. jubata* were examined and all were found to contain *C. villosum*. About 50 specimens were collected.

Corynosoma villosum was described by Van Cleave (1953) from *E. jubata* (the type host), *C. ursinus*, *Enhydra lutris* (the sea otter) and undetermined species of seals from various islands in the Bering Sea. The present specimens agree fully with the original description which was based on examination of more than 200 individuals.

ACARINA
Family HALARACHNIDAE Oudemans, 1906
Genus *Halarachne* Allman, 1847 emend. Newell, 1947
Halarachne sp.

Ten adult *P.v. richardi* from the Skeena River harboured a species of *Halarachne* in the nasal cavities. Only the hexapod larvae were found. The present material cannot be specifically identified since larvae of the three species of the genus *Halarachne* (*sensu stricto*) are apparently morphologically indistinguishable (Newell, 1947).

Two species of *Halarachne* have been reported from *P.v. richardi*. Doetschman (1941) recorded *H. miroungae* from this host in the San Diego Zoo, California, and Ferris (1942) recorded *H. halichoeri* [previously identified by Ferris (1925) as *H. otariae* Steding, 1923] from the same host in Pacific Grove, California and Nisqually, Washington State. Newell (1947) believes that Ferris' record is a misidentification and suggested that the specimens should probably be referred to *H. miroungae*. Scheffer and Slipp (1944), apparently on the authority of Ferris, listed *H. halichoeri* as a parasite of *P.v. richardi* in Washington State.

Genus *Orthohalarachne* Newell, 1947
Orthohalarachne diminuata (Doetschman, 1944) Newell, 1947 (Fig. 15)

This mite was found in the lungs (bronchioles) of the one *E. jubata* of which this organ was examined. The species was originally described by Doetschman (1944), as *Halarachne diminuata*, from *Zalophus californianus* of the California coast. Newell (1947) redescribed it in greater detail from specimens collected from *C. ursinus* at St. Paul Island, Alaska and placed it in his new genus, *Orthohalarachne*.

Prior to Newell's studies all mites parasitic in Pinnipedia were considered as belonging to one genus, *Halarachne* Allman. Newell transferred six species to *Orthohalarachne*, in all of which, except *O. diminuata*, the opisthosoma is attenuated or clavate in gravid females. In young specimens it is saccate. Since Newell did not examine females containing embryos he expressed uncertainty concerning the shape of the opisthosoma in gravid females. Doetschman did not state whether any of his females contained embryos. In the present collection there are females, up to 1050 microns long, carrying embryos in which the opisthosoma is saccate. It is apparent that in this species, the opisthosoma of gravid females does not become attenuated.

The sternal plate (Fig. 15) in the present specimens, conforms to Newell's description of this structure and the 3 pairs of sternal setae lie within the plate and not outside it as illustrated by Doetschman.

Eumetopias jubata is a new host record for *O. diminuata* and the finding of this parasite in British Columbia suggests a continuous distribution, through three different hosts, from Alaska to Southern California.

ANOPLURA

Family ECHINOPHTHIRIIDAE Enderlein, 1904
Genus *Echinophthirius* Giebel, 1871
Echinophthirius horridus (von Olfers, 1816) Ferris, 1916

This louse was not found in the present survey, but Fisher (1952) collected "about two dozen" lice from *P.v. richardi* pups from the Skeena River, from a pup from Ecstall River and from a yearling from Gibson Islands, British Columbia. The specimens were given to Professor G. J. Spencer of the University of British Columbia, who identified them as *E. horridus* (personal communication).
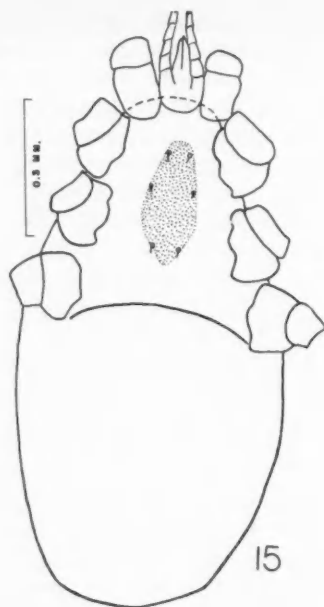
Fig. 15.—*Orthohalarachne diminuata*.
Ventral view showing sternal plate
and sternal setae.

This species was previously known from the northeast Pacific, Ferris (1934) having described it from *P.v. richardi* at Pacific Grove, California, and is apparently widely distributed on *P. vitulina* sub-spp. in the northern hemisphere.

For descriptions of the species, discussion on synonymy, and details of distribution and hosts reference is made to Freund (1928) Ferris (1934, 1951) and Hopkins (1946).

Genus *Antarctophthirus* Enderlein, 1906
Antarctophthirus microchir (Trouessart and Neumann, 1888) Enderlein, 1906

Both *E. jubata* pups examined were infected with *A. microchir*. Ferris (1916) identified *A. microchir* from *Z. californianus* and later (Ferris, 1934) published a brief description and included *E. jubata* from the California coast as another host. The species also has been recorded from *E. jubata* in Alaska (Jellison, 1952).

SUMMARY

The accompanying table summarizes and compares the species of parasites found in *Eumetopias jubata* and *Phoca vitulina richardi* in British Columbia seas. A + sign indicates the presence of the parasite and a — sign indicates its absence.

Parasite	Host		Organ infected
	E. jubata	*P.v. richardi*	
Cestoda:			
Diphyllobothrium pacificum	+	−	intestine
Diplogonoporus tetrapterus	+	−	intestine
Abothrium gadi	+	−	intestine
Nematoda:			
Terranova decipiens	+	+	stomach
Contracaecum osculatum	+	+	stomach
Parafilaroides sp.	+	−	lungs
Acanthocephala:			
Corynosoma villosum	+	−	intestine
Corynosoma strumosum	−	+	intestine
Acarina:			
Halarachne sp.	−	+	naso-pharynx
Orthohalarachne diminuata	+	−	lungs
Anoplura:			
Echinophthirius horridus	−	+	skin
Antarctophthirus microchir	+	−	skin

ACKNOWLEDGMENTS

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Diet-Induced Differences in the Weight—Length Relationship of Aquarium Fed Sardines (*Sardinops caerulea*)[1,2]

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INTRODUCTION

In the course of aquarium experiments designed to reveal diet induced changes (if any) in the free amino acid pool of fish muscle, some data were obtained on concurrent changes in the weight-length relationship of the fish fed on two different diets. The data and interpretation of these weight–length changes are presented here; the results and interpretation of the amino acid analysis will be presented elsewhere.

METHODS

In the spring of 1954 Steinhart Aquarium received approximately 1500 sardines (Radovich, 1954). These fish were taken in Hipolita Bay, Baja California, and are believed to be representative of a single population.

Four tanks were made available by the California Academy of Sciences for the experiments. Each was approximately 4 feet by 2 feet and 3 feet deep, and contained about 160 gallons of water. The tanks were made of leached redwood. Sand-filtered sea water was continuously cycled through the tanks. Throughout the course of the experiment the water temperature ranged from 66°–71°F., with a maximum daily range of $\pm 0.5°$F.

The four tanks (C_1, C_2, P_1, P_2) were each stocked with 25 sardines. These fish were withdrawn from the main stock tank without conscious selection. An additional sample of 25 sardines was sacrificed at the start of the experiment and are designated as "Control". These fish were in a starved or semi-starved condition. Fish in tanks C_1 and C_2 were fed a carbohydrate diet. Fish in tanks P_1 and P_2 were fed a protein diet. The fish were fed a ration of 4 grams (dry weight) of food per fish per day. The ration was divided into a morning and afternoon feeding.

The carbohydrate diet consisted of tapioca dyed red to simulate brine shrimp (upon which sardines will feed in captivity). This diet contained less than .0025 grams of amino acid per gram of food as determined by acid hydrolysis (Skinner *et al.*, 1940) and ninhydrin color test (Lederer and Lederer, 1953). The tapioca was about 90% carbohydrate. The protein diet consisted of fish meal, chicken eggs, vitamin supplement and fish liver oil. This material was homogenized and fed as dry pellets. On acid hydrolysis it yielded the following amino acids: aspartic acid, glutamic acid, glycine, threonine, alanine, tyrosine, trypto-

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phan, proline, leucine, valine, lysine and serine as determined by paper partition chromatography (Brimley and Barrett, 1954). This diet was about 57% protein and about 7% carbohydrate. No attempt was made to estimate the amount of micro flora and fauna in the tanks, but it was considered to be negligible.

The experimental fish were maintained on these diets for a period of six weeks and then sacrificed. Their weights and lengths were recorded, and body cavity fat was noted. A chromatogram was made of a sample of the pectoral muscle.

RESULTS

The weights and lengths of the 93 fish, distributed among five groups, are recorded in Appendix I. The fish which died (32) prior to the end of the experiment were not considered in the regression analyses (Fig. 1). The straight line
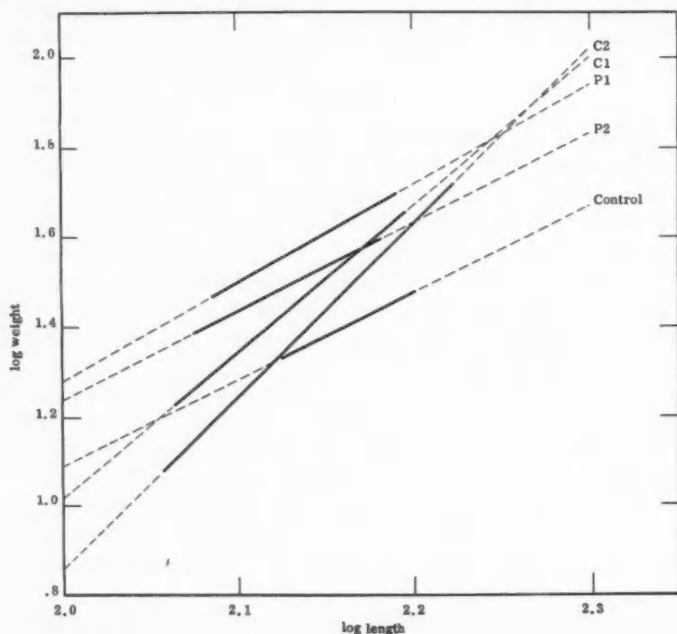
FIG. 1.—Log weight–log length regressions for five groups of sardines.

regressions of log weight on log length strongly suggest a difference in the weight–length relationship of the two diet groups. In order to test the reality of this difference, analysis of covariance procedures were used. (See any standard statistical text, such as Kendall, 1948.) The regression analyses are given in Tables I–IV and the regression statistics are summarized in Appendix II.

Comparison of diet group P_1 with diet group P_2 shows no difference in either slope or level of the regressions. The appropriate test is

$$F_{2,31} = \frac{S_2 + S_4}{df} \Big/ \frac{S_1}{df} = 0.138 < F_{2,31(.95)} = 3.3 \quad \text{(see Table I)}.$$

P_1 and P_2 data were combined and then used as a single regression, (P), since there was no difference in the log weight–log length regression of the fish in the two tanks.

The Control fish were then compared with P fish. The general test showed that there was a difference in slope and/or level

$$(F_{2,56} = 89.607 > F_{2,56(.95)} = 3.16).$$

The appropriate test for comparing slopes is

$$F_{1,56} = \frac{S_2}{df} \Big/ \frac{S_1}{df} = .0098 < F_{1,56(.95)} = 4.02;$$

the slopes do not differ. Comparison of levels,

$$F_{1,57} = \frac{S_4}{df} \Big/ \frac{S_1 + S_2}{df} = 182.372 > F_{1,57(.95)} = 4.01,$$

shows that they differ. The analysis is given in Table II.

Comparison of diet group C_1 with diet group C_2 showed that there was no difference in either slope or level (see Table III). These data were combined into a single regression ($C_1 + C_2 = C$).

The slope of groups P and Control, combined, were then compared with the slope of groups C, combined; the slopes proved to be different (Table IV).

In order to relate the experimental weight–length data to what may be considered a normal or natural condition, the weight–length data from the San Pedro fishery (Clark, 1928) were also plotted in Figure 2. The slope (3.15) of the San Pedro regression corresponds more closely with what was found for carbohydrate-fed fish (C_1, C_2) than with what was found for protein-fed fish.

TABLE I.—Sums of squares, products and regressions of log lengths (l) in millimeters and log weight (w) in grams for replicates of protein diet.

Source of variation	Degrees of freedom	Σl^2	Σw^2	Σlw	Regression coefficients
Within P_1	15	.0116028	.1030096	.0255327	2.20056
Within P_2	18	.0186601	.1088586	.0367610	1.97003
Within P_1 and P_2	33	.0302629	.2118682	.0622937	2.058418
Between groups	1	.0018125	.0115132	.0045679	2.52022
Totals	34	.0320754	.2233814	.06686159	2.084513

	Degrees of freedom	Sums of squares	Mean squares
Deviations from individual regression	31	$S_1 = .0832616$	.00269729
Differences between slopes of individual regressions	1	$S_2 = .0003802$	.0003802
Deviations from regression with common slope	32	$S_1 + S_2 = .0836418$	.00261381
Deviations of groups from means regression	0	$S_3{}^* = .00000$	...
Difference between slope of means regression and common slope	1	$S_4 = .0003657$	.0003657
Totals	33	.0840075	...

*S_3 has been retained throughout to indicate the extent of the rounding error.

TABLE II.—Sums of squares, products and regressions of log lengths (l) in millimeters and log weights (w) in grams for protein diet and "control".

Source of variation	Degrees of freedom	Σl^2	Σw^2	Σlw	Regression coefficients
Within P	34	.0320753513	.2233814	.0668615873	2.084516
Within "Control"	24	.0084951362	.0854757	.0172041547	2.025177
Within Groups	58	.0405704875	.3088571	.0840657420	2.072091
Between Groups	1	.0001371141	.4010019	−.007415033	−54.07929
Totals	59	.0407076016	.7098590	.076650689	1.88296

	Degrees of freedom	Sums of squares	Mean squares
Deviations from individual regression	56	$S_1 = .1346415$	.002404313
Differences between slopes of individual regressions	1	$S_2 = .0000236$	.0000236
Deviations from regression with common slope	57	$S_1 + S_2 = .1346651$	.002362546
Deviations of groups from means regression	0	$S_3 = .00000$	...
Difference between slope of means regression and common slope	1	$S_4 = .4308639$	.4308639
Totals	58	.5655290	...

TABLE III.—Sums of squares, products, and regressions of log lengths (l) in millimeters and log weights (w) in grams for replicates of carbohydrate diet.

Source of variation	Degrees of freedom	Σl^2	Σw^2	Σlw	Regression coefficients
Within C_1	12	.0148485	.1691975	.0488010	3.287713
Within C_2	19	.0354281	.5734579	.1356846	3.829858
Within C_1 and C_2	31	.0502766	.7426554	.1845022	3.669743
Between Groups	1	.0047144	.0866812	.0202148	4.287883
Totals	32	.0549910	.8293366	.2047170	3.722736

	Degrees of freedom	Sums of squares	Mean squares
Deviations from individual regression	29	$S_1 = .0625044$	.0021553
Differences between slopes of individual regressions	1	$S_2 = .0030753$	.0030753
Deviations from regressions with common slope	30	$S_1 + S_2 = .0655797$	.00218599
Deviations of groups from means regression	0	$S_3 = .0000$	...
Difference between slope of means regression and common slope	1	$S_4 = .001649$	.001649
Totals	31	.0672292	

TABLE IV.—Sums of squares, products and regressions of log length (l) in millimeters and log weight (w) in grams for protein diet-control and carbohydrate diet.

Source of variation	Degrees of freedom	Σl^2	Σw^2	Σlw	Regression coefficients
Within C	32	.0549910	.8293366	.2047170	3.72274
Within Control	59	.0407076	.7098590	.0766507	1.88296
Within Groups	91	.0956986	1.5391956	.2813677	2.94014
Between Groups	1	.0225600	.3800211	.0925906	4.10419
Totals	92	.1182586	1.9192167	.3739583	3.16221

	Degrees of freedom	Sums of squares	Mean squares
Deviations from individual regression	89	$S_1 = .6327582$	.00710964
Differences between slopes of individual regressions	1	$S_2 = .0791757$	.0791757
Deviations from regression with common slope	90	$S_1 + S_2 = .7119339$	.007910377
Deviations of groups from means regression	0	$S_3 = 0.0000$	...
Differences between slope of means regression and common slope	1	$S_4 = .0247488$	.0247488
Totals	91	.7366827	
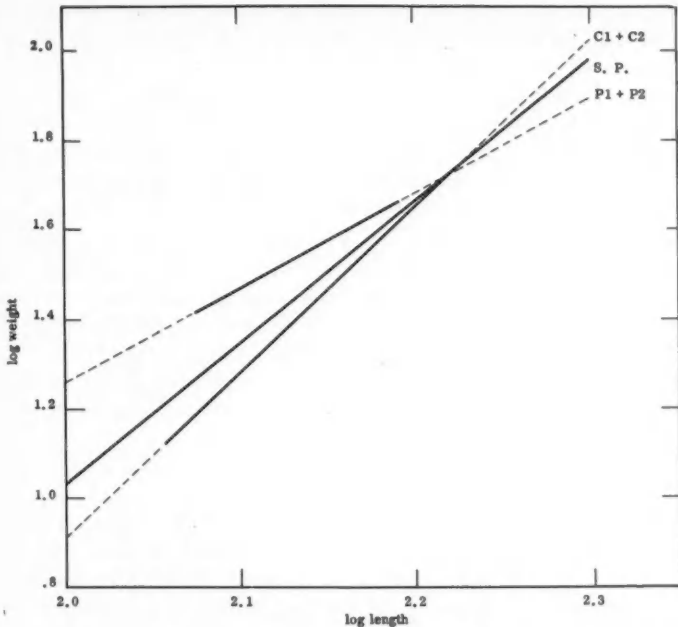
Fig. 2.—Log weight–log length regressions for three groups of sardines.

From dissection of the fish, the following was observed: Control fish were in generally poor condition with no body fat. The carbohydrate-fed sardines (C_1 and C_2) were in a better condition with traces of body fat. The protein-fed fish (P_1 and P_2) were in good condition with fat in the body cavities of all specimens.

DISCUSSION

It is quite possible that the apparent gain in weight of the carbohydrate-fed fish is due to an accelerated uptake of water. It is to be noted, however, that the postulated uptake of water exceeded that of mere replacement. One is also perplexed by the fact that the larger fish added a disproportionately larger weight increment of their body weight when fed on a carbohydrate diet. Unfortunately, the fish were destroyed before the data were analyzed. However, an alternative hypothesis may be devised from the following considerations.

The differences in slope of the regressions are then to be regarded as real. In nature a sardine diet is mainly zooplankton (Radovitch, 1952), which is relatively high in protein. This type of diet gives rise to a weight–length regression having a slope of about 3.0 to 4.0. It is inferred that during starvation the larger fish lose weight at a greater rate than do smaller fish (because they have more fat stores to use), resulting in a lesser slope of the regression of log weight on

log length. This would produce a regression similar to Control in slope. Now if these starved fish suddenly receive a "normal" to excess ration containing protein nitrogen (as in the P_1 and P_2 groups), it is possible that this added protein nitrogen brings about an increased cell production resulting in an increase in length. If, on the other hand, the "normal" to excess ration contains little or no nitrogen (as in the C_1 and C_2 groups), then the increase may be limited to the cells already present. The cells could increase their fat and carbohydrate stores up to a maximum, but no new cells could be added. This being the case, carbohydrate-fed fish would approximate the normal weight–length relationship more quickly than those fed on protein diet where lineal growth is possible. Had the fish fed on protein been maintained for a longer period of time, this weight–length regression should have the same slope as the normal, but the means should be displaced upward and to the right (i.e., the level would be greater). The lesser slope of the regression for protein-fed fish may be regarded as the result of a short term enhancement of cell production induced by the sudden flooding of the starved organisms with protein nitrogen.

SUMMARY

1. The weight–length relation of lots of 25 sardines fed different diets were compared. The diet history of these fish was (1) starved or semi-starved (one lot), (2) protein diet (two lots) and (3) carbohydrate diet (two lots).

2. The weight–length regressions of the two protein-fed lots do not differ in slope or level.

3. The weight–length regressions of the protein-fed fish (both lots combined) and the starved (Control) lot differ in level, but not in slope.

4. The weight–length regressions of the two lots of carbohydrate-fed fish do not differ in slope or level.

5. The weight–length regressions of protein-fed and Control fish (three lots combined) and the carbohydrate-fed fish (both lots combined) differ in slope.

6. The slope of the weight–length regression of carbohydrate-fed fish more closely approximates that of "wild" fish landed at San Pedro, than does the slope of the protein-fed fish.

7. The increase in weight of the carbohydrate-fed fish may be due to water uptake.

8. These observations may be explained by the fact that the carbohydrate-fed fish were able to increase their stores of fat and carbohydrate but were not able to add new cells, whereas the protein-fed fish were able to add new cells and thus increase in length.

able the facilities of Steinhart Aquarium. Mr. Bruce Taft, U.S. Fish and Wildlife Service, aided in the preparation of the statistics.

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APPENDIX I.—Lengths and weights of sardines surviving at the end of the experiment.

Control		C_1		C_2		P_1		P_2	
Length	Weight	Length	Weight	Length	Weight	Length	Weight	Length	Weight
mm.	grams	mm.	grams	mm.	grams	mm.	grams	mm.	grams
144	24	116	15	143	30	130	29	151	52
140	22	157	41	117	16	145	35	150	36
149	28	143	32	131	18	148	50	145	45
147	30	145	37	123	18	155	49	145	37
142	26	148	31	167	52	122	28	135	37
135	27	142	30	135	24	151	34	148	38
141	18	122	19	123	20	142	40	152	41
141	26	129	21	126	20	139	36	149	40
139	22	141	32	120	12	144	39	149	38
139	22	131	24	121	16	142	35	129	31
149	26	136	27	131	22	150	34	128	31
147	29	137	28	114	12	149	52	119	24
136	24	139	30	122	19	150	40	148	41
152	30			152	38	155	46	137	42
144	24			138	27	153	49	143	37
134	25			114	12	147	46	140	36
154	32			126	23			129	31
146	28			143	36			147	33
140	25			120	18			125	28
141	21			136	31				
147	28								
159	31								
133	23								
143	28								
143	28	12 died		5 died		9 died		6 died	

APPENDIX II.—Regression statistics for all groups of fish. The regression coefficients a, b, and residual variance $s^2_{y.x}$ apply to logarithmic values of X and Y.

	n	$\bar{X}$	$\bar{Y}$	a	b	$s^2_{y.x}$
Control	25	143	26	−3.05	2.07	0.002201
C_1	13	137	27	−5.56	3.29	0.0007908
C_2	20	129	21	−7.08	3.83	0.002989
P_1	16	145	39	−3.12	2.20	0.003345
P_2	19	140	36	−2.70	1.97	0.002143
$C_1 + C_2$	33	132	23	−6.42	3.67	0.0024112
$P_1 + P_2$	35	142	37	−2.90	2.08	0.002387
San Pedro	..	...	..	−6.73	3.15	...

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Indices of Productivity in British Columbia Lakes[1]

By T. G. Northcote[2] and P. A. Larkin[3]

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ABSTRACT

The relation between physical and chemical indices of production and standard crops of plankton, bottom fauna and fish was examined in 100 British Columbia lakes. A significant increase in plankton and fish quantities with increase in total dissolved solid content of lake waters was demonstrated and a similar relationship suggested for bottom fauna. Although the general form of the relationship between mean depth and plankton, and between bottom fauna and fish quantity, suggested a hyperbolic curve with larger quantities in lakes of low mean depth, the only generalization which seemed justified was that quantities of fauna from lakes of great mean depth were never as high as those found in *some* lakes of low mean depth. No significant relation was found between intensity and length of growing season and quantities of plankton, bottom fauna or fish, although a significant relationship was demonstrated between summer epilimnion temperature and plankton.

In a multiple regression analysis using all lakes the predominance of total dissolved solids over mean depth in affecting summed indices of lake fauna was shown. However for lakes in the southern interior plateau, one of the 9 regions distinguished in British Columbia, no significant relation could be demonstrated between mean depth or total dissolved solids and summed indices of fauna or plankton alone. Thus total dissolved solid content of the water appeared to be the most important factor in determining the general level of productivity in lakes studied throughout the province, although within a region neither total dissolved solids nor mean depth could be used either singly or together to predict plankton, bottom fauna or fish quantities.

INTRODUCTION

DISTINCTION of factors affecting lake productivity and their interrelationships have been the concern of much limnological research. Although the effects of a multitude of physical and chemical factors upon the production of organic matter within lakes have been demonstrated, predominance often has been assigned to some particular factor within a geographical region. Thus Thienemann (1927) and more recently Rawson (1952, 1953a, 1953b) have stressed the importance of lake morphometry, while the significance of geology and dissolved nutrients have been emphasized especially by Naumann (1932), Deevey (1940) and Moyle (1946).

British Columbia is a highly varied geographic area exhibiting marked diversity in geology and climate. The wide range in morphometric, edaphic and climatic features encountered in lakes of this province make it a suitable region

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in which to examine the relative importance of various factors affecting lake productivity.

The limnological data for the present study were collected in the course of a lake and stream survey program initiated in 1949 by the British Columbia Game Commission. Data on lake morphometry, readily measurable physical and chemical characteristics, and sample estimates of abundance of plankton, bottom fauna and fish were collected for 100 lakes. Raw survey data with less complete information on about 100 additional lakes are available on file at the University of British Columbia offices of the B.C. Game Commission.

While most of the limnological survey material is not sufficiently complete nor intensive to permit accurate quantitative study, the large body of information is useful for observing the relation between physical and chemical indices of production and observed abundance of lake fauna. A suggested distinction of various limnological regions in the province is also developed.

ACKNOWLEDGMENTS

METHODS

In the majority of instances, all limnological data for a particular lake were collected in one short survey lasting from two or three days to as long as three weeks, depending on the size of the lake. In some cases lakes were visited more than once. Limnological information for most of the 100 lakes here considered, included a sounding map, tabulated calculations of area, mean depth and volume, a water sample for mineral analysis, vertical temperature series, water transparency, dissolved oxygen determinations, total vertical plankton hauls, a series of bottom fauna samples, gill net samples of fish and observations of a general nature which seemed pertinent. The data for any one lake are not necessarily representative of any particular stage in the growing season or the thermal cycle. Lakes were not surveyed in any particular order, except possibly as they were conveniently located for planning an itinerary during the summer period. In general, lakes in one large district were studied in one calendar year, but there was probably no bias for investigating certain types of lakes at certain times of the year.

The following brief notes indicate details of the techniques employed and some limitations of the data.

LAKE MORPHOMETRY:— Soundings were taken with a hand winch and wheel-and-axle counter or in some cases with a marked hand line. Locations were determined by timed runs of an outboard motor boat. Positions were later plotted on an outline map expanded from aerial photographs, and contours were drawn at appropriate intervals. Areas of the various strata were determined with a polar planimeter, and volumes between strata estimated using the formula $V = h A_2 + \frac{1}{2}h(A_1 - A_2)$, where V is volume, h the depth between strata, and A_1, A_2 the area of the upper and lower strata, respectively.

WATER SAMPLES:— Samples of lake water were collected immediately below the surface, where possible near the centre of the lake. Most of the samples were analysed by the Chemistry Division of the British Columbia Research Council for total dissolved solids, specific conductivity, Ca, K, Mg, Fe, Na, SO_4 and Cl. In some samples total dissolved solids were determined by correlation with specific conductivity measured by a type R. C. conductivity bridge. The British Columbia Research Council determined the relationship between total dissolved solids and specific conductivity, and suggested the latter measurement as a convenient method for rapidly assessing dissolved solid content of the lake waters.

TEMPERATURE, OXYGEN AND TRANSPARENCY:— Vertical temperature series were taken with a Model FA–190011 Wallace and Tiernan bathythermograph or with Taylor maximum–minimum thermometers. Oxygen determinations were made by the Winkler method. Water transparency was measured by Secchi-disk readings.

PLANKTON:— Samples were taken in vertical tows with No. 10 mesh Wisconsin type nets at stations selected near the centres of the lakes. Settled volume of plankton was determined in calibrated centrifuge tubes, allowing a 24-hour period for settling. Where samples for several collections from different times and places were available for a lake each sample was given equal weight in computing a mean.

BOTTOM FAUNA:— Samples were taken by means of either 6-inch or 9-inch Ekman dredges at representative depth zones and washed through a 30-mesh per linear inch screen. Counts or notes on abundance of organisms were made in the field; samples were preserved in formalin for later examination. In view of limited sampling and the extreme variability connected with quantitative bottom fauna determinations, the data were treated only in a general manner. From notes and counts made in the field, and from examination of preserved samples in the laboratory, the lakes were classified into three categories with respect to quantities of bottom fauna taken in dredgings.

Bottom fauna was considered sparse when numbers of organisms taken per 9-inch dredging averaged 10 or less, moderate when between 11 and 25, and abundant when over 25. No attempt was made to weight for area of depth zone from which samples were taken.

FISH:— Samples were collected by gill nets and where possible by seine hauls. Gill nets (chiefly cotton) were set in gangs of eight nets ranging in stretched mesh size from 1½ to 5 inches at intervals of ½ inch. Each net was 50 yards long and 2 yards deep. Sunken sets were made for overnight periods, generally 12 to 14 hours. Weight, fork length, sex and condition of maturity were recorded and scale samples and stomach contents were collected for all fish taken.

A measure of relative abundance of fish was made on the basis of mean weight in kilograms of all fish caught per overnight set of a standard gang (1½ to 5 inch) of gill-nets. Appropriate allowance was made where a particular mesh size was duplicated but no correction was applied if one mesh size was not fished. The young of all species, and adults of several species of small cyprinids, cottids, sticklebacks and other groups were not included in this method of sampling. Seine hauls were not taken in all lakes so no quantitative estimate of abundance of small fish was attempted. Although the method of sampling is undoubtedly crude for quantitative purposes, catches may be expected to reflect major differences between lakes in abundance of "nettable" fish.

Comparisons of lakes with respect to numbers or weight of fish is particularly subject to error in British Columbia because of major differences in distribution of species of fish. Most of the low lying coastal lakes have a relatively large number of species of fish, as do many lakes of the interior valleys and northern interior plateau. However, in the many small lakes of the southern interior plateau and in mountainous areas of the province, the only fish occurring are those which have been artificially stocked. The lakes do not share even approximately comparable fish faunas. This factor undoubtedly contributes also to different degrees of utilization of the plankton and bottom fauna crops.

DISSOLVED NUTRIENTS AND PRODUCTIVITY

The effects of a variety of dissolved compounds and elements in determining lake productivity have been considered under the "edaphic" factor. Through a detailed investigation of the geology, soils, and lake sediments, Naumann (1932) classified lakes of southern Sweden according to types of contrasting productive levels. Deevey (1940) has shown the importance of total phosphorus content of lake waters in limiting plankton production in Connecticut. Moyle (1946) has related fish production in a number of Minnesota lakes to their total alkalinity and total phosphorus content. Rawson (1951) attributed much of the difference in plankton, bottom fauna, and fish production between Great Slave and Great Bear Lakes, and between two distinct areas of Great Slave itself, to contrasting total dissolved solid contents. Möller (1955) has presented maps of total dissolved solid content of waters of southwestern Germany, and believes that this measurement is not only useful as a preliminary means of evaluating the nutrient content of lake waters but may also serve as an indicator of lake typology. The total dissolved content determinations (T.D.S.) for the British Columbia lakes were related to quantities of plankton, bottom fauna and fish.

PLANKTON

In an arithmetic plot (not shown) of mean settled plankton volumes on total dissolved solids, a marked "fanning" of distribution at higher values of T.D.S. was evident, indicating a proportionality between means and variances. Accordingly, data were transformed to logarithms (Snedecor, 1946). In this analysis there was a significant regression of log plankton volume on log T.D.S. ($P < 0.01$). The plotted points and the line of best fit, $Y = 0.372X - 0.388$ are shown in Figure 1. Standard error of the regression coefficient was 0.089.

Although the variability was considerable, there was a trend for lakes with moderate to high dissolved solid contents (above 100 p.p.m.) to have higher volumes of plankton than lakes whose T.D.S. was low. No lakes in which the dissolved solid content was below 50 p.p.m. showed volumes exceeding 5 cc. However, in the lake with highest dissolved solids, Lillian, the volume of plankton was below 5 cc., so a high T.D.S. did not appear to be invariably associated with large plankton volumes.

BOTTOM FAUNA

The relation between the three levels of bottom fauna abundance and dissolved solid content is shown for 87 lakes in Table I. Sparse bottom faunas were confined to waters with T.D.S. less than 180 p.p.m., and were most often recorded
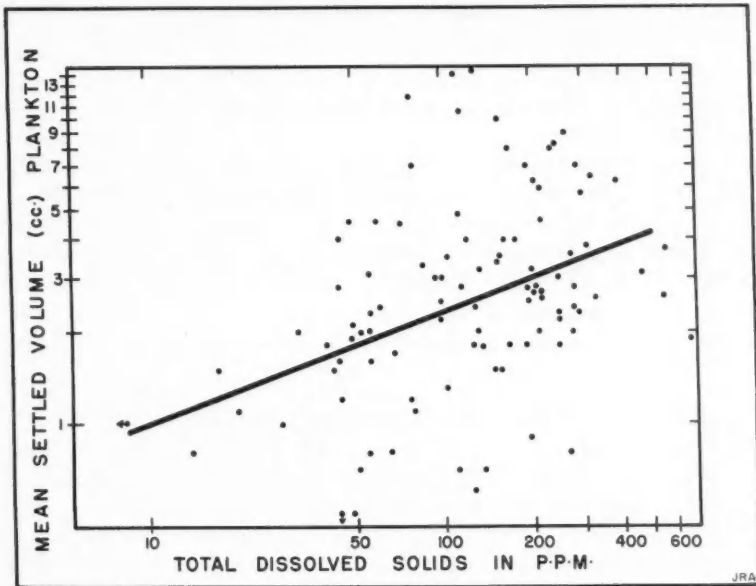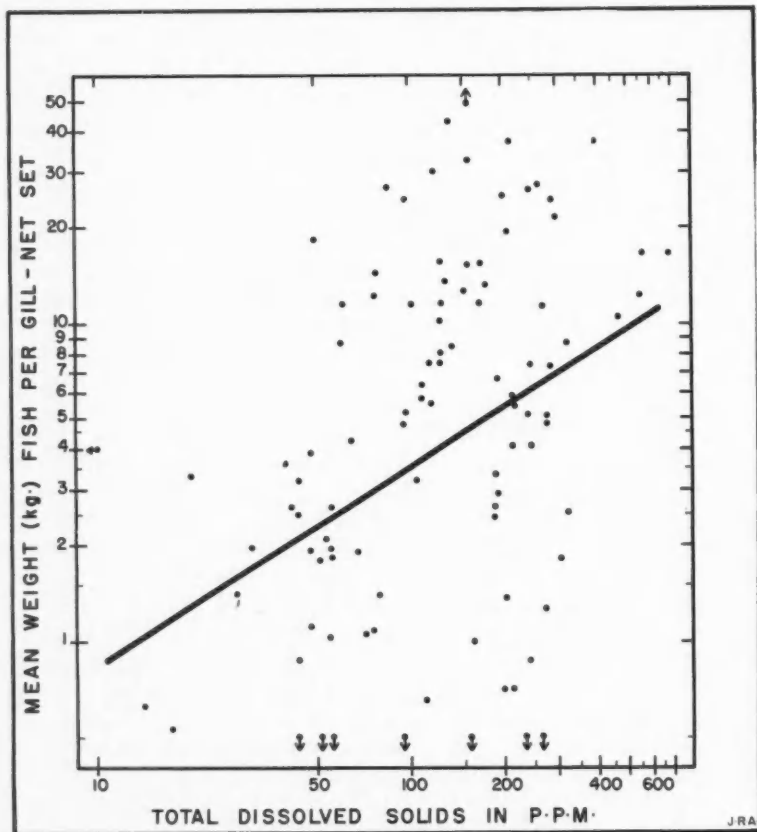
Fig. 1.—Relationship between total dissolved solids and quantities of plankton in 100 British Columbia lakes. (Logarithmic axes, points with arrows lie beyond limits of axes shown.)

TABLE I.—Bottom fauna abundance in relation to total dissolved solid content in 87 British Columbia lakes.

Total dissolved solid content (p.p.m.)	Lakes with sparse bottom fauna	Lakes with moderate bottom fauna	Lakes with abundant bottom fauna
0– 30	4	1	—
31– 60	14	6	—
61– 90	3	5	—
91–120	5	4	—
121–150	1	3	3
151–180	2	2	3
181–210	—	6	2
211–240	—	4	2
241–270	—	4	2
271–300	—	1	4
Over 300	—	3	3

in lakes with less than 60 p.p.m. Lakes exhibiting moderately abundant bottom faunas were present in all class intervals of T.D.S., while abundant bottom faunas were found only in lakes with T.D.S. above 120 p.p.m. Thus a trend is suggested for increasing abundance of bottom fauna with increasing T.D.S., although the relationship is not precise.

FISH

An analysis using logarithmic transformation of data gave a significant regression of fish weight on T.D.S. (P < 0.01). The plotted points and line of best fit, Y = 0.618X — 0.684 are shown in Figure 2. Standard error of the regression coefficient was 0.221.

In general, larger gill-net catches of fish were taken in lakes with moderate to high T.D.S. (over 100 p.p.m.), than in lakes where T.D.S. was low. Lakes with T.D.S. less than 50 p.p.m. appeared to be particularly unproductive in respect to fish (no catches in this group exceeded 4 kg.); however low catches were also made in a few lakes of relatively high dissolved solid content.

FIG. 2.—Relationship between total dissolved solids and quantities of fish in 100 British Columbia lakes. (Logarithmic axes, points with arrows lie beyond limits of axes shown.)

LAKE MORPHOMETRY AND PRODUCTIVITY

Since Thienemann (1927) emphasized the role of mean depth in lake typology, this feature has been used in most limnological studies as the best single criterion of lake basin morphometry. Rawson (1939) felt that the mean depth of a lake is probably "its most significant dimension", and has stressed its importance in plankton, fish, and bottom fauna production (Rawson, 1952, 1953a, 1953b). In the present study, "littoral development" (obtained by expressing the area of the lake less than 30 feet deep as a percentage of the total surface area), as suggested by Rawson (1939), was considered in addition to mean depth. However the relationship between "littoral development" and quantities of plankton, bottom fauna and fish was very similar to that found for mean depth and only the latter determination has been used in subsequent comparisons.

PLANKTON

The relation between mean settled volumes of plankton and mean depth for 100 British Columbia lakes is shown in Figure 3a. The general form of the distribution of points suggested a "hyperbolic relationship" similar to that described by Rawson (1953a). There was no significant regression in these data when transformed to logarithms. In the arithmetic plot, 14 out of 15 lakes with mean depths exceeding 100 feet, showed plankton volumes below 5 cc. Low volumes also appeared frequently in lakes with mean depths less than 100 feet; thus 68 of the 85 lakes in this latter group showed plankton volumes under 5 cc. Large volumes of plankton (above 5 cc.) occurred chiefly in lakes with mean depth less than 60 feet, in which group 14 of 17 lakes had plankton volumes in excess of 5 cc.

Thus, the "hyperbolic relationship" between mean depth and plankton quantity is largely based on a few lakes of high mean depth with low plankton quantities and a few lakes of low mean depth with abundant plankton. Rawson (1953a) has interpreted the occurrence of lakes with plankton quantities well below or above expected values as the result of unfavourable or favourable edaphic and climatic conditions. This interpretation could be applied to the present data, e.g. many lakes with mean depths less than 30 feet and plankton volumes below 2 cc. had low total dissolved solid contents. Such examples could be multiplied by considering other factors, but quantitatively this would do little to improve the relation between mean depth and standing crops of plankton. The only generalization justified here is that in lakes of relatively high mean depths, say above 150 feet, amounts of plankton are never as high as those which *may* be found in lakes of low mean depth.

BOTTOM FAUNA

Table II gives the relation between three major levels of bottom fauna abundance and mean depth for 87 lakes. High and moderate numbers of bottom organisms occurred most often in lakes with mean depth less than 75 feet. Of 18 lakes with mean depth over 75 feet, only 2 showed an abundant bottom fauna. Sparse bottom faunas were found in some lakes of each mean depth group.
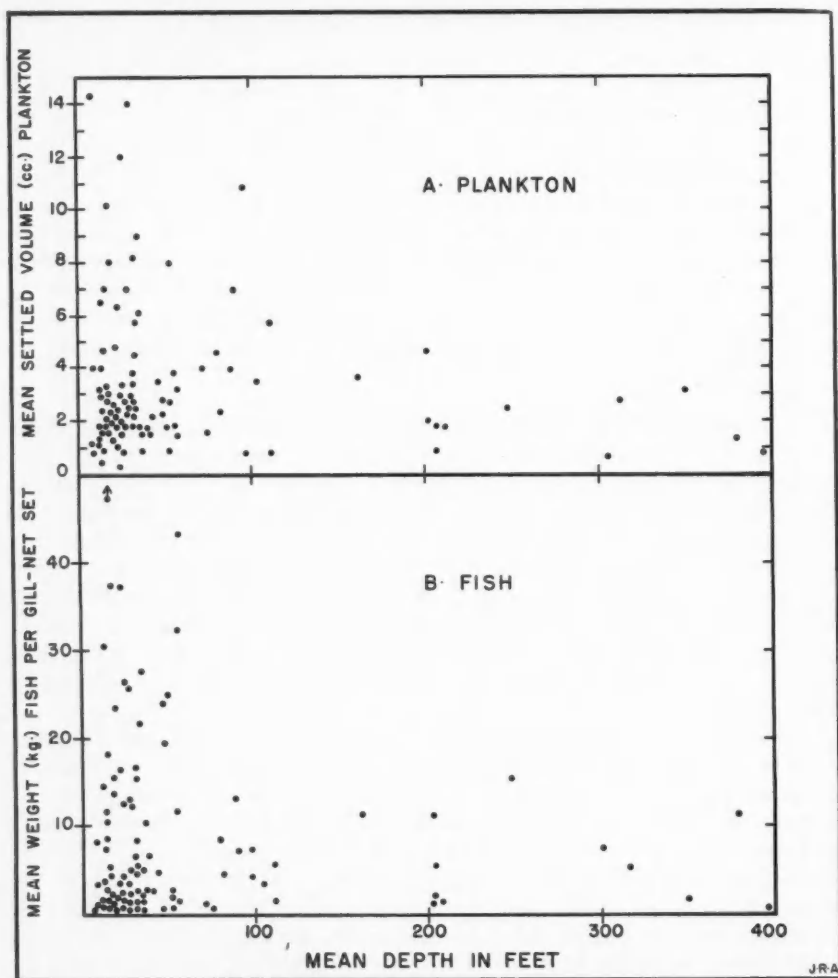
Fig. 3.—Relationship between mean depth and quantities of plankton and fish in 100 British Columbia lakes. (Points with arrows lie beyond limits of axes shown.)

Rawson (1930) demonstrated a hyperbolic curve relating average crop of bottom fauna to lake depth and area. Deevey (1941) plotted bottom fauna against mean depth for 116 lakes of temperate latitudes. The resulting plot resembled a hyperbola, but as neither hyperbolic nor exponential functions could be fitted to it, he concluded that the hyperbolic form was a result of combining diverse bodies of data in each of which there was no correlation. Moreover,

TABLE II.—Bottom fauna abundance in relation to mean depth in 87 British Columbia lakes.

Mean depth (feet)	Number of lakes with sparse bottom funa	Number of lakes with moderate bottom fauna	Number of lakes with abundant bottom fauna
25 and under	11	19	5
26– 50	6	10	9
51– 75	1	5	3
76–100	2	1	—
101–200	2	1	1
201–300	3	2	1
Over 300	4	1	—

he was able to demonstrate a significant *positive* correlation between mean depth and bottom fauna in 33 small Connecticut lakes.

Rawson (1953b) has found an apparent negative correlation (hyperbolic curve) between dry weight of bottom fauna and mean depth in 10 large North American lakes. Here two lakes of low mean depth (less than 20 metres) showed high weights of bottom fauna (over 12 kg/ha), while 8 of mean depth over 20 metres showed weights of bottom fauna less than 6 kg/ha. He concluded that the relationship between mean depth and standing crop of bottom fauna is applicable only to deep lakes and even there may be widely variable. In the present data the only conclusion suggested is that lakes of mean depth over 75 feet rarely have abundant bottom fauna while lakes of lesser mean depth *may* have abundant bottom fauna.

Mean weights of fish per gill-net set are plotted against mean depths of 100 lakes in Figure 3b. There was no significant regression in these data when transformed to logarithms. The arithmetic distribution obtained is similar to that shown for plankton. In lakes with mean depths greater than 60 feet, gill-net catches never exceeded 16 kg. while 17 lakes with lower mean depths showed catches well beyond this range. However, in a large number of lakes with low mean depth, fish catches were as low or lower than those in extremely deep lakes.

Rawson (1952) has fitted a hyperbolic curve to the relation between mean depth and fish production in 13 large lakes. He obtained a fairly good fit with the shallower lakes (less than 60 feet), although Lake Erie, which had the greatest mean depth of this group also showed the highest production of fish. Unfortunately, no data were available for lakes in the mean depth range between 60 and 180 feet, but by extending the two arms of this curve, Rawson gave the dividing point of inflection of the hyperbola as near 59 feet. If a hyperbolic relationship were considered applicable in Figure 3b, the point of inflection would probably occur near 60 feet. In any event, in lakes beyond this mean depth fish catches were never as high as found in *some* lakes of lower mean depth. Thus it appears that mean depth alone may not be a reliable indicator of relative abundance of fish in the shallower, eutrophic range (less than 60 feet), but above this range some limitation in crops occurs.

CLIMATE AND PRODUCTIVITY

General features of the climatic factor and lake productivity have been outlined by Rawson (1939) and related to standing crops of plankton and bottom fauna in several western Canadian lakes (Rawson 1942).

The effects of precipitation on lake productivity are largely dependent upon the geology, morphometry and cover of the lake's drainage area. In regions of hard, insoluble substrate, high precipitation and low evaporation probably do not favour concentration of dissolved nutrients and in conjunction with high flushing rates within the lake basins, adversely affect productivity. However, in areas of softer, exposed and more soluble substrate the effects of high precipitation could be quite different. In view of the complex action of precipitation and the difficulty in interpreting effects of high or low rainfall on productivity in different regions of the province, precipitation has not been considered separately in the present study.

Data on wind velocities and direction have been recorded from only a few stations in British Columbia. Because local topographic differences between stations and most lakes are so great, the data are of little value in estimating effects of wind on lake productivity.

Solar radiation is of two-fold importance as a climatological factor in productivity, first as the source of light directly necessary for photosynthesis by plants, and second as the source of heat determining water temperature which may regulate the speed of living processes. Only the latter aspect of solar radiation, temperature, will be considered in the following discussion.

Effects of the heat component of solar radiation may be expressed in two major ways: (1) by the *average* water temperature for the entire "growing season", (2) by the temperature *attained* in the growing season, particularly that of the epilimnion.

Growing Season

An adequate measure of the average temperature of a lake, i.e., the intensity and length of the growing season, would require records of water temperature over the whole growing period. In the absence of such data, use was made of air temperatures given in the Monthly Record of Meteorological Observations published by the Meteorological Division of the Canada Department of Transport. In a few instances, unpublished data were supplied by field stations of the Canada Department of Agriculture. Where temperature data could be obtained in the vicinity of a particular lake but at an elevation differing by more than 500 feet, adjustments were made using lapse rates of 3°F./1000 feet for coastal areas and 4°F./1000 feet for the interior of the province. These rates seemed most suitable in consideration of the work of Baker (1944) and some unpublished data for British Columbia provided by Professor J. D. Chapman, of the University of British Columbia.

The single measure used as an index of the growing season was the annual sum of the degrees by which the mean daily air temperatures exceeded a base temperature of 50°F. The base of 50°F. was chosen for two reasons. Firstly, using

50°F. as a base meant a summing of temperature for a period corresponding roughly to the ice free period of the lakes. A 40°F. base was too low and would suggest a growing season extending well into the period of ice cover. A 60°F. base was too high; some lakes would scarcely record any growing season while the majority would be lumped in one category reflecting the short and very hot midsummer period. A second reason for using the 50°F. base was provided by use of data from Great Slave Lake given by Kennedy (1953) for the common whitefish (*Coregonus clupeaformis*) and Kennedy (1954) for the lake trout (*Salvelinus namaycush*). Measures of growing seasons on bases of 40°, 50° and 60°F. were compared to Kennedy's data for seasonal accumulated growth curves for the two species of fish. The base of 50°F. gave the best fit to the growth data.

Measures of growing season (the annual sum of the degrees by which mean daily air temperature exceeded 50°F.) were plotted against the abundance of plankton, bottom fauna and fish respectively. In each case no clear relationship was apparent and chi-square analyses confirmed that none of the plots departed significantly from randomness. Presumably length and intensity of growing season is related more to annual production than to standing crops of animals in lakes.

SUMMER EPILIMNION TEMPERATURE

Rawson (1942) showed that plankton quantity in several western Canadian lakes appeared to be related more closely to the mean temperature of the 0–10 metre stratum in midsummer than to that of the whole lake. Mean temperature of the 0–30 feet stratum was calculated for the British Columbia lakes where summer (July 15–September 15) determinations were available (Appendix I) and these temperature values were plotted against plankton, bottom fauna, and fish quantities. No correlation was apparent between bottom fauna or fish quantities and mean summer epilimnion temperature. However, greater plankton volumes appeared to be found in lakes with higher epilimnion temperatures. A regression analysis using a logarithmic transformation indicated a significant relationship $Y = 2.490X - 3.9746$, standard error of the regression coefficient $(s_b) = 1.131$, $P = 0.02–0.05$, but the regression was not close (Fig. 4).

MULTIPLE INDICES OF PRODUCTIVITY

Although some degree of association can be demonstrated in relating features of the physical environment with major components of the lake biota, (such as mean depth and plankton), indices of this kind have major short-comings as measures of lake productivity. With respect to biotic factors, they measure only one part of the lake fauna, and with respect to the physical factors, they arbitrarily assign first significance to one of a complex of factors. An attempt has been made with the present data to devise multiple indices of productivity that would allow comparisons of lakes on the bases of their biota as a whole or their physical and chemical characteristics as a group.

As a single measure representing most of the biological production in a lake, a combined index was devised—the "bio-index". It was the sum of relative
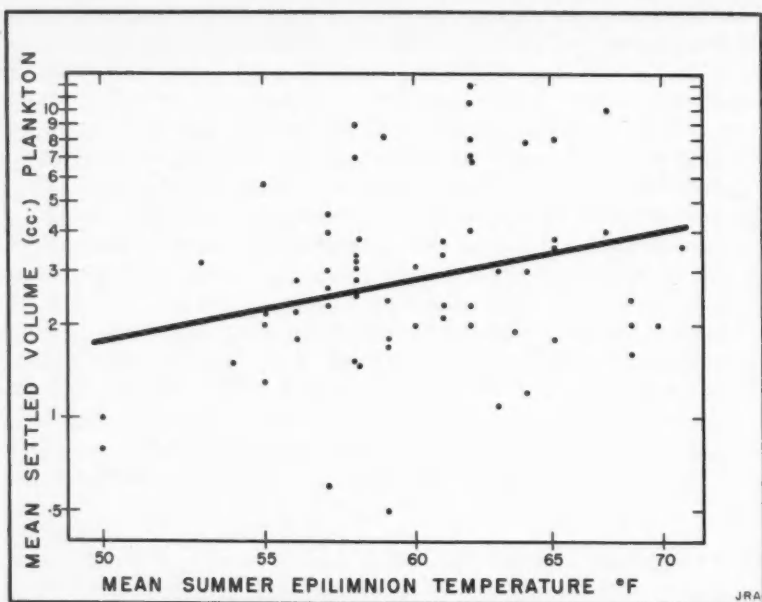
Fig. 4.—Relationship between summer water temperature (0–30 feet) and quantities of plankton in 63 British Columbia lakes. (Logarithmic axes.)

measures of plankton, bottom fauna and fish abundance. Ten classes of relative abundance were drawn up for plankton quantities, designating as class 1, plankton volumes of less than 1 cc., class 2 — volumes from 1 to 2 cc., and so on to class 10 — volumes over 9 cc. The three levels of bottom fauna abundance previously described, 0–10, 11–25 and over 25 organisms per dredging, were designated as class 1, class 5 and class 10 respectively. Mean weights of fish caught per gill-net set were divided into 10 classes; those below 2 kg. were class 1, from 2 to 4 kg. class 2, and so on to class 10—above 18 kg. The bio-index for a particular lake was the sum of the class numbers for plankton, bottom fauna and fish. It is not suggested that the total biota of a lake is comprised one-third each of plankton, bottom fauna and fish. Rather, each of these three elements of the biota is given equal weight as a measure of appraising the lakes' level of productivity.

Physical and chemical factors were similarly classified. Ten classes of total dissolved solid content were recognized. Using a 30 p.p.m. class interval, lakes with T.D.S. content of less than 30 p.p.m. were placed in class 1, those of over 270 p.p.m. in class 10. Similarly 10 classes of a mean depth were devised using a class interval of 10 feet, but in this case the lowest measures (shallowest lakes) were given the highest class values. Lakes with a mean depth of 10 feet or less were in class 10, those of 90 feet or more were in class 1. Because of the poor relation of climate to plankton, bottom fauna and fish (and to bio-index) no further analyses with climatic data were attempted.

The classified data of bio-index, mean depth and total dissolved solid content for 87 lakes from all parts of the province were analysed using multiple regression techniques (Snedecor, 1946). The resulting regression equation was:

$$Y = 0.39590X_1 + 2.96599X_2 - 5.71198,$$

where Y = bio-index, X_1 = mean depth, X_2 = total dissolved solid content. ($R^2 = 0.32846$; standard regression coefficient for $X_1 = 0.07938$, for $X_2 = 0.55440$; standard error of the standard regression coefficients = 0.09070). The entire regression and the X_2 (T.D.S.) coefficient are significant but the mean depth coefficient, X_1, is not significant. For data for the province as a whole T.D.S. was over 7 times as powerful as mean depth in forecasting bio-index.

At the suggestion of Dr. W. E. Ricker the multiple regression of bio-index, mean depth and total dissolved solid content was repeated using logarithms. The resulting equation was:

$$Y = -0.06607X_1 + 0.38585X_2 + 0.54453$$

where $Y = \log_{10}$ bio-index, $X_1 = \log_{10}$ mean depth and $X_2 = \log_{10}$ T.D.S. ($R^2 = 0.42857$; standard regression coefficient for $X_1 = -0.09818$, for $X_2 = +0.64208$; standard error of standard regression coefficients = 0.08223.)

Thus considering mean depth did not significantly improve the relationship between T.D.S. and bio-index. The change in sign of the mean depth coefficient from positive in the regression on classified data to negative in the logged data merely reflects that the deepest lakes were given the smallest class numbers. In both regressions an increase in mean depth is weakly associated with a decrease in bio-index.

From this analysis it was suggested that any effect of mean depth on productivity would be evident only in comparisons of lakes with total dissolved solid content similar both in quantity and quality. Further multiple regression analyses are described below for data for several lakes in a particular district.

REGIONAL AREAS AND PRODUCTIVITY

Regions of British Columbia have widely different geological substrate, topography and climate. Physiographic regions of the province have been distinguished by Brink and Farstad (1949). Climatic characteristics of different parts of the province have been given by Chapman (1952a, 1952b). Munro and Cowan (1947) have distinguished biotic areas in British Columbia. With recognition of these schemes of subdivision and in consideration of similarities of dissolved solid content of the lake waters, it is possible to subdivide the province into areas in which some homogeneity in physical and chemical conditions which affect lake productivity might be anticipated. Figure 5 indicates the location of the regions which have been distinguished for this study, while Figures 6–9 show some typical lakes, from most of the regions. Figure 10 shows the mean bio-index for lakes in each district plotted against their respective mean total dissolved solid index. Ranges for both indices are also given for each group of lakes. Briefly, the regions are described as follows:
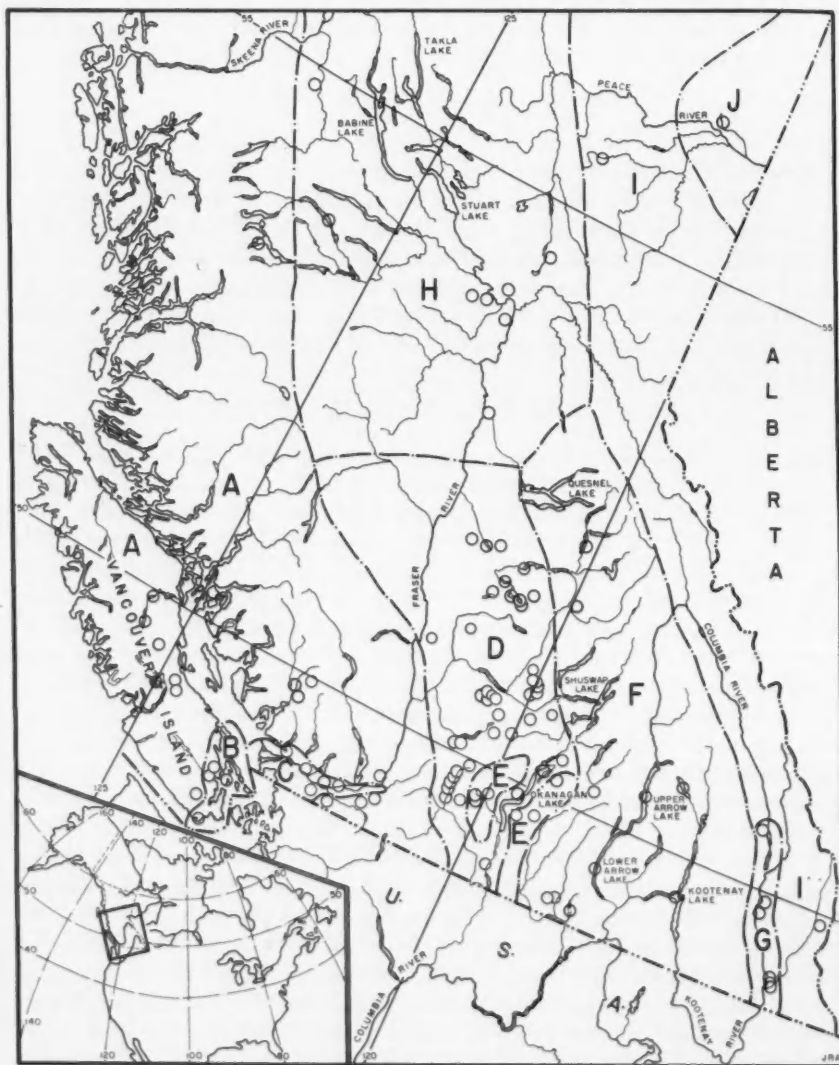
Fig. 5.—Limnological regions distinguished in British Columbia. A, Coast and Insular Mountains; B, Insular Lowland; C, Lower Fraser Valley; D, Southern Interior Plateau; E, Southern Interior Highland; F, Columbia Mountains; G, Southern Rocky Mountain Trench; H, Northern Interior Plateau; I, Rocky Mountains; J, Tramontane Plains. Inset shows geographic location of area. Circles show the location of lakes studied in each region.

FIG. 6.—Above: Buttle Lake—Coast and Insular Mountains.
Below: Hatzic Lake—Lower Fraser Valley.
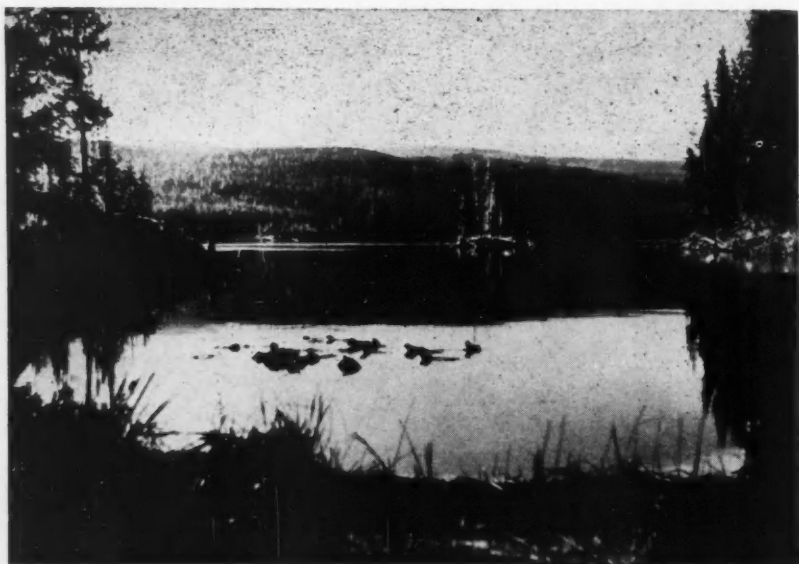
Fig. 7.—Above: Oyama Lake—Southern Interior Highland.
Below: Premier Lake—Southern Rocky Mountain Trench.

FIG. 8.—Above: Quamichan Lake—Insular Lowland.
Below: Alleyne Lake—Southern Interior Plateau.
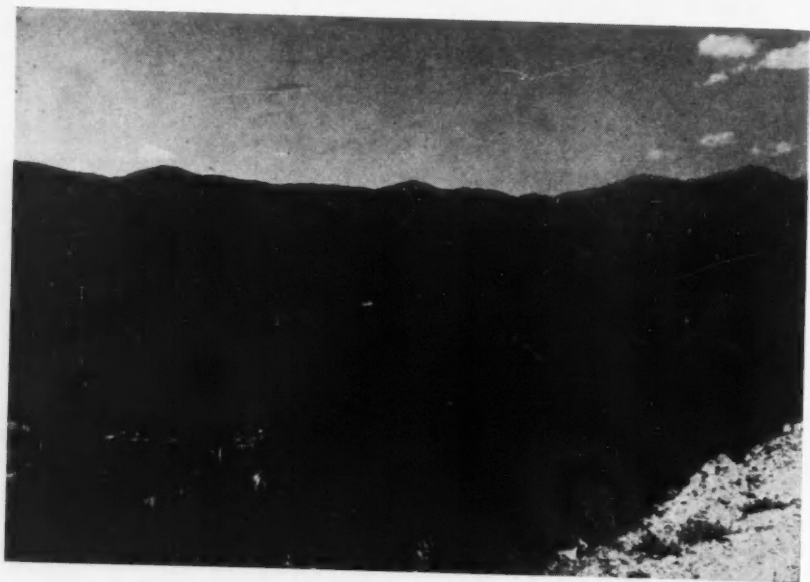
Fig. 9.—Above: Christina Lake—Columbia Mountains.
Below: Azouzetta Lake—Rocky Mountains.
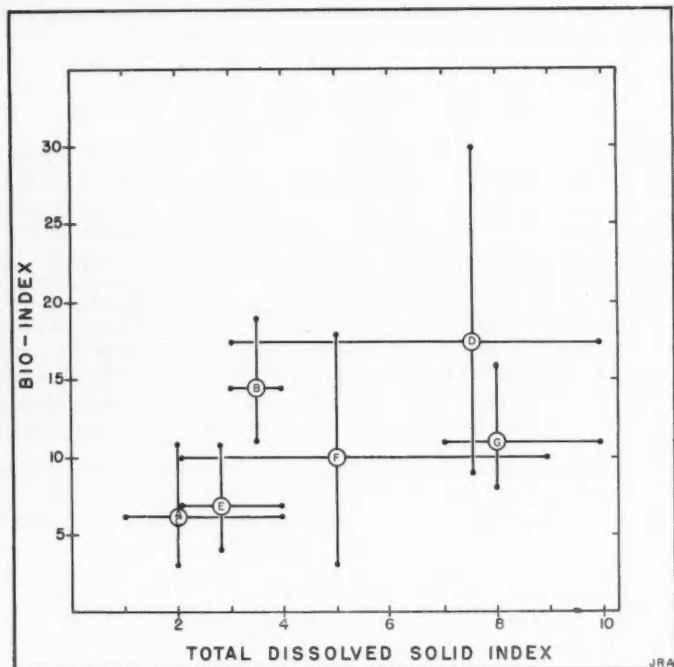
Fig. 10.—Mean and range of total dissolved solid indices and bio-indices for 7 regions in British Columbia. A, Coast and Insular Mountains; B, Insular Lowland; C, Lower Fraser Valley; D, Southern Interior Plateau; E, Southern Interior Highland; F, Columbia Mountains; G, Southern Rocky Mountain Trench.

A. COAST AND INSULAR MOUNTAINS:—Mountains of Vancouver Island and coast of mainland. Island mountains largely resistant metamorphic, volcanic and sedimentary rocks intruded by irregular bodies of granitic rocks. Coast mountains mostly granitic intrusives (Clapp, 1912, 1913, 1914). Recently glaciated, typical basins of large lakes are steep sided, fiord-like (Fig. 6, upper). Climate maritime, high rainfall with tendency for summer minimum, cool summers, mild winters except at high elevations (5,000–10,000 feet). The 17 lakes studied in this district showed a low T.D.S. averaging 46 p.p.m., reflecting the high precipitation, and the resistant rocks of surrounding formations. High "flushing rates" are typical (McMynn and Larkin, 1953; Robertson, 1954). Bio-indices ranged from 3 to 11. Fish and bottom fauna were typically low, plankton variable.

B. INSULAR LOWLAND:—East coast lowland of Vancouver Island and Gulf Islands. Corresponds to Gulf Islands Biotic area (Munro and Cowan 1947). Sedimentary deposits eroded from insular mountains. Largely overlain with glacial till and interglacial sediments. Elevations less than 400 feet. Moderate precipitation (25 to 40 inches) warm dry summers, mild moist winters. Four lakes studied in this district had T.D.S. average of 91 p.p.m. Low mean depth of these lakes is characteristic. Bio-indices ranged from 11 to 19 and were made up of moderate plankton and bottom fauna but poor fish values.

C. LOWER FRASER VALLEY:—Delta of Fraser river below Hope. Corresponds to Puget Sound Lowlands biotic area (Munro and Cowan 1947). Alluvial and marine deposits uplifted in postglacial era overlying glacial till and interglacial sediments (Johnston 1921). Elevations below 700 feet. Climate like insular lowlands at valley mouth but heavier rainfall close to flanking coast mountains and valley head. Six lakes studied in this area, average T.D.S. 44 p.p.m., characteristically with low mean depth. Low bio-indices.

D. SOUTHERN INTERIOR PLATEAU:—Sounthern plateau area between coast range on west and Columbia Mountains on east. Mostly sedimentary and volcanic rocks extensively glaciated and with mantle of lucustrine silts in many areas (Mathews 1944, Schofield 1943). Mostly gently rolling uplands at elevations of 3000 to 6000 feet, with deeply dissected valley trenches. Low annual precipitation, marked June maximum and March-April minimum; extreme temperatures vary with latitude and elevation. Of 33 lakes studied, only one had T.D.S. less than 100 p.p.m. and average T.D.S. was 229 p.p.m. Low to moderate mean depths typical. Bio-indices ranged from 9 to 30 (the latter is the highest bio-index possible). Mean bio-index was 18, made up of high plankton and bottom fauna values but variable fish quantities, the latter largely reflecting absence of many fish species from high altitude lakes.

E. SOUTHERN INTERIOR HIGHLAND:—West and east Okanagan Highlands zone of Brink and Farstad (1949), lying at elevations over 3000 feet in the upper Okanagan river drainage. Higher precipitation, cooler summers, longer, more severe winters than adjacent plateau and valleys. Sub-alpine Forest biotic area (Munro and Cowan 1947). Six lakes studied in this area all with T.D.S. less than 100 p.p.m., average T.D.S. 70 p.p.m. and all with brown stained water. Low values for plankton, bottom fauna and fish all contribute to low bio-indices.

F. COLUMBIA MOUNTAINS:—Between interior plateau on the west and the Rocky Mountain trench on the east and extending north to Quesnel system, roughly corresponding to extent of Columbia Mountains. Highly metamorphosed sedimentary and volcanic rocks with extensive granitic intrusions, valleys overdeepened by pleistocene glaciation and with local glacial till deposits (Gunning 1943). Precipitation high, marked winter maximum and summer minimum. Elevations range from 1500 to 9000 feet. A varied area with diversity of lake types in which further subdivision is suggested. Ten lakes in the area showed a wide range in bio-index, T.D.S. and mean depth.

G. SOUTHERN ROCKY MOUNTAIN TRENCH:—The narrow valley bordering the Rocky Mountains on the west. A distinctive area with substrate largely glacial deposits derived from adjacent ranges. Terraces of silt and gravel typical. A recurrence of Dry Forest biotic area (Munro and Cowan 1947). Low precipitation, severe winters and dry summers. Elevations range from 2500 to 3500 feet. Six lakes studied in this area had T.D.S. average of 285 p.p.m. and mean depth average of 25 feet. Except for one lake, bio-indices were lower than would be anticipated, ranging from 8 to 16.

H. NORTHERN INTERIOR PLATEAU:— Headwaters for tributaries of Peace, Skeena and Fraser rivers; lowlying plateau centred around Prince George. Geology like southern plateau, climate more severe in winter, cooler in summer. For 8 lakes studied, bio-indices available for only two. These suggest moderate productivity despite low to moderate T.D.S.

I. ROCKY MOUNTAINS:—Between Rocky Mountain Trench and Great Divide. Largely sedimentary formations with extensive recent glaciation. Climate continental, severe winters, cool summers, moderate precipitation. Only two lakes studied in this area but see also Rawson (1942). Moderate to high mean depths and low to moderate T.D.S. content contribute to low bio-indices.

J. TRAMONTANE PLAINS:—A distinct physiographic area, the north-western extension of the interior continental plains. Cretaceous sedimentary rocks underlie quaternary gravels, silts and clay (Allan and Stelck, 1940). Annual precipitation is low with a marked summer concentration. Severe winters, moderately warm summers. High T.D.S. and low mean depth in one lake studied whose bio-index was also high (25).

Most of the limnological regions distinguished above are represented by such a few lakes that multiple regression analyses were precluded. Moreover, many of the regions should probably be subdivided to limit the wide variations which reflect the complex local geology and topography of the province.

However, the Southern Interior Plateau seemed a suitable subdivision for analysis. It was represented by 33 lakes, and except for a moderate difference in climate from north to south, it was reasonably homogeneous.

Three separate multiple regression analyses were made on the data from the Southern Interior Plateau region. The first was done on class values for mean depth (x_1), T.D.S. (x_2) and bio-index (y). There was no significant multiple regression ($R^2 = 0.069$) nor any significant coefficient for T.D.S. and bio-index ($b = 0.052$, $s_b = 0.177$). The coefficient for mean depth ($b = 0.257$, $s_b = 0.177$) was not significant ($P = 0.1$–0.2) but suggested a weak negative correlation between mean depth and productivity (a weak positive correlation in the class data where lowest mean depth was the highest class value). The second regression was done with raw data for mean depth and T.D.S. and class values for bio-index, in anticipation that proper consideration of extreme values might either confirm or deny the mean depth-bio-index relationship suggested in the first analysis. This regression gave essentially the same results ($R^2 = 0.058$) failing to show a significant multiple regression or a significant mean depth coefficient. The third analysis was done on logarithmic data for mean depth, T.D.S. and plankton volumes, the latter being the measure of lake fauna that showed the best correlation with physical and chemical factors among the single regressions treated in the earlier part of this paper. Again no significant multiple regression was demonstrated, nor were either of the regression coefficients significant. The mean depth coefficient was smaller than in previous analyses, while the T.D.S. coefficient was weakly negative, suggesting if anything an inverse relation of T.D.S. and plankton!

In conclusion, mean depth and total dissolved solid content cannot be used singly or in combination in the present data to predict the size of standing crops of organisms in lakes within this region of the province.

DISCUSSION

Early investigators of lake productivity were often impressed by the importance of a single factor in determining productivity in their region. Thienemann (1927) stressed the importance of lake-basin morphometry, particularly mean depth, and set up a classification of lake types emphasizing this feature. Naumann (1932), for lakes of southern Sweden, felt that the chemical nature of lake waters, as determined by their geological surroundings, was of primary significance. More recently, Rawson (1939) has illustrated the interrelation of factors which may affect lake productivity. Despite the complexity and interaction of these factors, Rawson suggests that they may be grouped into three major categories, morphometric, edaphic, and climatic. The morphometric factor is concerned with size and shape of a lake basin, especially mean depth. The edaphic factor deals with quantity and quality of dissolved nutrients present

in the water, while climatic factor includes the varied effects of precipitation, wind, and solar radiation upon the lake. None of these factors acts independently. Assessing their separate and combined effects on production of plankton, bottom fauna and fish, which are also interrelated, is the essential problem in studying lake productivity.

The climatic factor can be conveniently considered first. In some of its aspects climate is reflected by total dissolved solid content. In areas of high precipitation and low evaporation rate (such as the Coast and Insular Mountain area of British Columbia) rapid flushing out of lakes and a heavy demand on soil nutrients by a lush ground cover, may contribute to low T.D.S. as much as the relative insolubility of the surrounding rocks. Conversely, the low annual precipitation and the hot dry summers of the Southern Interior Plateau area cause concentration of dissolved nutrients in basins which frequently have no evident outflow.

Climate appears to have less influence on the size of maximum standing crop of lake organisms than on the number of crops which are produced in a year. Thus, in the lakes under consideration there is no apparent correlation of air temperatures with standing crops of plankton, bottom fauna and fish, but the protracted growing season of low-altitude lakes probably would be reflected in their annual production, particularly by comparison with some of the high alpine lakes of the province. The direct effect of climate is to determine length of the growing season rather than the size of the standing crop. Indirect climatic effects acting on and in conjunction with the surrounding substrate may greatly influence standing crops by determining total dissolved solid content.

Edaphic conditions are reflected in lake productivity chiefly by the quantity and quality of dissolved nutrients. Presumably, most elements occur in excess of the biological demand in lake water, but seasonal shortage of some elements may limit the size that the standing crop may attain. Excluding sampling error, the precision of correlations of T.D.S. with quantities of organisms may depend on (a) differences in quality of dissolved nutrients (b) the extent to which some part of the dissolved solid content is limiting production (c) obtaining samples at comparable maximum points of the growing season. Considering the variability in geological substrate, the possibilities for limitation of standing crops by factors other than T.D.S. and the likelihood that samples were not taken at comparable times, the regressions of T.D.S. on lake biota that have been demonstrated are surprisingly good. Dissolved nutrients must rank as a primary factor in determining levels of productivity.

However, the failure of T.D.S. to show correlation with standing crops of organisms except where there is a very wide range of T.D.S. (i.e. in the province-wide regressions) suggests need for considering other factors, chief among which is mean depth. Measures of lake morphometry give an assessment of the suitability of a lake environment for aquatic organisms, of which a great many forms are adapted to a shallow water existence. In addition, lake shape and size influence circulation of heat, nutrients and dissolved gases and thus indirectly may control the speed and magnitude of growing processes. It would

appear that in these roles lake morphometry, as a factor influencing productivity, is not adequately expressed by mean depth. Apparently, extensive littoral bottom fauna production contributes a large fraction to total productivity only in very shallow lakes. In lakes with an intermediate mean depth, loss of littoral zones may be offset by more extensive plankton and profundal bottom fauna production. Probably only in the deepest and largest lakes do factors of lake morphometry such as mean depth significantly deter production. Thus in an area homogeneous with respect to total dissolved solids, no relation of mean depth to standing crops of organisms could be demonstrated unless there was a wide range of mean depth with the extreme values well represented. Considering lakes throughout the province, edaphic factors as measured by total dissolved solid content of the water appear to be most important in determining the general level of productivity.

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APPENDIX I.—Physical, chemical, and biological data for 100 British Columbia lakes

LAKE	Regional[1] Location	Altitude (feet)	Mean depth (feet)	Littoral development (%)	Maximum depth (feet)	Surface area (acres)	Total dissolved solids (P.P.M.)	Mean summer temperature 0–30 FT. (°F.)	Annual[2] day-degree units	Mean settled volume plankton total vertical No. 10 net (cc.)	Bottom fauna[3] abundance	Mean weight (kg.) all fish caught per gill-net set	Bio-Index
Abbotsford	L.F.V.	30	13	88	43	43	48	59	1650	0.5	S	4.0	4
Alice	C.I.M.	550	32	78	55	28	44	—	1652	2.8	M	2.5	10
Alleyne	S.I.P.	3250	55	15	117	135	308	65	815	3.8	M	1.8	10
Allison	S.I.P.	2700	49	35	128	175	202	58	1066	2.8	M	19.3	18
Azouzetta	R.M.	2850	44	39	98	340	97	56	388	2.2	S	4.8	7
Borgeson	S.I.P.	2600	34	26	59	38	295	55	1066	5.7	A	21.9	26
Bridge	S.I.P.	3700	57	47	154	8642	134	58	1036	3.2	A	43.1	24
Brohm	C.I.M.	1000	37	66	78	31	17	—	1407	1.5	S	0.6	4
Buttle	C.I.M.	710	201	<10	396	7648	48	—	1433	4.6	M	1.2	11
Cameron	C.I.M.	604	97	8	131	1180	65	—	1600	0.8	M	4.2	9
Canim	S.I.P.	2515	247	9	608	20237	129	—	800	2.4	S	15.6	12
Chain	S.I.P.	3500	14	100	20	115	120	67	615	4.0	M	30.3	20
Charlie	T.P.	2270	16	99	33	6860	155	67	1060	>10.0	M	3356.2	25
Chimney	S.I.P.	2700	31	47	62	1218	558	61	800	3.7	—	16.6	—
Christina	C1.M.	1500	111	5	160	6496	55	—	1864	0.8	S	1.0	3

[1]C.I.M.   = Coast and Insular Mountains
I.L.   = Insular Lowland
L.F.V.   = Lower Fraser Valley
S.I.P.   = Southern Interior Plateau
S.I.H.   = Southern Interior Highland
N.I.P.   = Northern Interior Plateau
Cl.M.   = Columbia Mountains
S.R.M.T.   = Southern Rocky Mountain Trench
R.M.   = Rocky Mountains
T.P.   = Tramontane Plains.

[2]Annual sum of the degrees by which mean daily air temperatures exceeded a base temperature of 50° F.

[3]S   = Sparse,   0–10 Organisms per dredging (81 sq. in.)
M = Moderate,   11–25   "   "   "   "
A = Abundant.   >25   "   "   "   "

Clearwater	Cl.M.	2480	317	6	611	28105	117	—	847	2.8	S	5.0	7
Cluculz	N.I.P.	2480	97	24	200	6223	118	62	858	10.7	—	7.6	—
Comox	I.C.M.	440	>210	7	>328	4937	48	64	1771	1.9	S	1.9	4
Crystal	S.I.P.	3700	25	>75	53	135	150	58	1036	1.5	M	12.9	14
Cultus	C.I.M.	145	104	9	137	1550	104	—	1751	3.5	S	3.2	7
Dempsey	S.I.P.	2970	33	48	92	329	138	59	666	1.8	—	8.4	—
Dougan	I.L.	100	21	76	33	105	112	58	1881	4.8	M	0.6	11
Dragon	N.I.P.	2500	19	100	28	1627	210	68	1032	2.0	—	37.9	—
Dry	S.I.P.	2600	25	76	52	64	243	57	1066	3.0	A	26.8	24
Dutch	Cl.M.	1000	46	50	134	157	155	65	1447	3.5	S	0	6
Echo	Cl.M.	2670	55	27	157	174	167	—	1280	1.8	A	11.7	18
Eulatazella	N.I.P.	2600	19	96	43	1100	130	60	858	2.0	—	13.8	—
Eutsuk	C.I.M.	2817	350	<10	1000	61594	56	58	—	3.1	S	1.9	6
Garibaldi	C.I.M.	4816	396	5	849	2457	14	50	183	0.8	S	0.6	3
Grave	R.M.	4140	52	52	87	341	190	—	486	1.8	M	2.6	9
Hansen	S.R.M.T.	2300	17	87	45	283	213	—	1090	2.8	M	4.2	11
Hatzic	L.F.V.	10	8	94	55	909	44	62	1901	4.0	M	0.9	11
Heart	N.I.P.	2000	14	99	31	155	95	64	790	3.0	—	0.3	—
Heffley	S.I.P.	3095	36	45	77	501	206	—	848	6.2	M	1.4	13
Horne	C.I.M.	302	74	13	164	2094	44	68	1771	1.6	S	0.1	4
Horse	S.I.P.	3700	50	35	118	2872	201	—	1036	2.7	A	25.0	23
Hyas	S.I.P.	4060	27	62	72	159	196	56	520	2.8	M	3.4	10
Idabel	S.I.H.	4200	19	79	42	110	56	57	425	2.3	S	2.0	5
Jacko	S.I.P.	2900	29	52	75	100	550	—	1050	2.6	A	12.3	20
Jewel	Cl.M.	3710	37	34	70	203	127	—	580	0.7	M	10.3	12
Kalamalka	S.I.P.	1293	162	9	430	6512	270	70	1925	3.6	M	11.4	15
Kathlyn	N.I.P.	1650	15	99	31	420	49	61	922	2.1	S	18.3	14
Kawkawa	L.F.V.	150	33	33	48	189	72	—	2025	4.5	M	1.0	6
Kemp	I.L.	150	15	100	29	67	80	58	1131	7.0	M	1.4	14
Kentucky	S.I.P.	3250	53	33	120	108	232	65	815	8.0	M	0.1	15
Knouff	S.I.P.	3768	32	52	79	254	152	61	587	3.4	A	15.4	22
Kootenay	Cl.M.	1745	>200	<10	531	98560	127	—	1400	1.8	—	11.7	18
Lac des Roches	S.I.P.	3720	56	48	145	4520	153	58	1036	1.5	—	32.7	—
Lac la Hache	S.I.P.	2650	48	54	122	5685	283	61	1100	2.3	A	24.2	23
Laird	S.I.P.	2600	33	48	69	77	276	59	1066	2.4	A	4.8	16
Lequime	S.I.H.	3891	17	91	45	99	68	59	574	1.7	S	1.9	4
Lillian	S.R.M.T.	3200	22	60	42	68	686	—	889	1.9	M	16.7	16
Link	S.I.H.	3600	12	100	17	46	79	63	615	1.1	S	14.7	11
Loon	S.I.P.	2820	90	17	213	2374	283	62	800	7.0	—	7.2	—
Lower Arrow	Cl.M.	1379	>200	<10	551	40499	110	—	1415	0.7	M	5.7	9
Madden	S.I.P.	2000	32	46	65	27	244	55	1501	2.2	M	0.9	9
McCaffery	S.I.P.	2650	20	'88	36	16	322	57	1066	2.6	A	2.5	15
McConnell	S.I.P.	4242	35	54	84	80	260	58	550	9.0	A	27.6	30
Missezula	S.I.P.	3200	89	17	216	691	176	57	815	4.0	S	13.1	13
Monte	S.I.P.	2245	71	18	119	436	160	—	1300	4.0	M	1.0	11
Nadsilnich	N.I.P.	2000	26	54	50	1242	78	62	790	12.0	—	12.3	—
Ness	N.I.P.	2000	20	71	60	503	98	58	858	2.5	—	24.6	—
North Star	S.R.M.T.	2700	15	82	36	124	213	—	1401	4.6	M	0.7	11
Ootsa	N.I.P.	2710	80	<10	300	30592	60	57	—	4.6	S	8.8	11
Osprey	S.I.H.	3606	15	84	33	92	96	63	615	3.0	S	5.2	8
Oyama	S.I.H.	5000	22	73	64	900	44	—	400	1.2	M	3.5	9
Paul	S.I.P.	2542	112	10	182	985	212	64	1435	5.9	A	5.6	19
Pavilion	S.I.P.	2500	83	18	184	647	244	62	1463	2.3	—	4.1	—
Pemberton	S.I.P.	4040	17	77	43	31	200	53	520	3.2	—	0.7	—
Peterhope	S.I.P.	3650	38	52	108	287	192	62	600	7.0	A	6.6	22
Pillar	S.I.P.	2889	27	53	52	107	85	58	1280	3.3	M	26.1	19
Pinantan	S.I.P.	2859	33	41	62	161	238	59	1435	8.2	A	5.3	22
Premier	S.R.M.T.	3000	52	32	105	567	189	—	1090	0.9	M	2.4	8
Prudhomme	C.I.M.	93	37	52	150	635	42	54	749	1.5	S	2.6	5
Quamichan	I.L.	101	14	100	23	754	61	68	1839	2.4	M	11.7	14
Rainbow	C.I.M.	100	24	37	66	603	4	50	749	1.0	S	4.0	6
Rosen	S.R.M.T.	2700	14	85	42	180	193	—	1401	2.5	M	2.9	10
St. Mary	I.L.	150	30	51	55	482	110	—	1748	14.0	M	6.3	19
Salmon	S.I.P.	3070	19	71	39	304	168	62	836	8.0	A	15.5	27
Schkam	C.I.M.	1350	25	39	44	99	56	—	1898	2.0	S	0	5
Shannon	S.I.P.	1700	27	58	62	45	276	—	1673	2.8	A	5.0	16
Shawnigan	C.I.M.	380	35	58	128	1468	40	65	1761	1.8	S	3.6	5
Sheridan	S.I.P.	3600	25	68	107	10063	272	62	1036	2.0	M	1.3	9
Shumway	S.I.P.	2240	23	64	40	228	392	—	1598	6.3	—	37.5	—
Silver	C.I.M.	1000	23	56	42	98	44	—	1408	0.1	M	2.1	8
Sproat	C.I.M.	95	>200	5	640	13447	32	69	1692	2.0	S	2.0	5
Squakum	L.F.V.	47	12	100	26	64	28	—	1901	1.0	M	1.4	8
Stake	S.I.P.	4323	14	100	29	57	465	60	550	3.1	A	10.2	20

Summerland Reservoir 1	S.I.H.	4100	11	100	18	141	76	64	400	1.2	S	1.1	4
Surveyors	S.R.M.T.	2500	28	54	63	116	216	—	1400	2.6	M	5.7	11
Swan	S.I.P.	1175	14	100	29	1014	320	—	1925	6.5	M	8.8	17
Trout	Cl.M.	2247	380	<10	825	—	102	55	—	1.3	S	11.7	9
Upper Arrow	Cl.M.	1401	>300	<10	948	56704	127	57	1242	0.6	M	7.6	10
Upper Campbell	C.I.M.	650	40	29	130	1562	56	—	1500	1.6	S	2.6	5
Wahleach	C.I.M.	2100	20	79	62	697	52	55	1106	2.0	M	1.8	9
Walloper	S.I.P.	4300	9	100	25	90	128	—	550	14.2	A	8.1	25
Watch	S.I.P.	3700	14	100	32	646	242	56	1036	1.8	M	7.3	11
Welcome	L.F.V.	100	7	100	14	11	51	—	1932	0.7	S	0.3	3
Whonock	L.F.V.	250	8	100	30	112	20	—	1823	1.1	S	3.4	5
Wilgress	Cl.M.	2000	25	56	50	39	266	—	1113	0.8	M	0.2	7

Notes on Polychaeta from the East Coast of Vancouver Island and from Adjacent Waters, with a Description of a New Species of *Aricidea*[1]

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ABSTRACT

Records are given of two species and a variety new to western Canada and notes on three other species already known from the region. A new species, *Aricidea lopezi,* and four species new to western North America, are described from the neighbourhood of Friday Harbour, Washington.

SYLLIDAE
Eusyllis magnifica (Moore)

Moore, 1906, p. 223 (as *Pionosyllis*); Pettibone, 1954, p. 261.

This is a new record for the coast of western Canada. A small specimen (about 15 mm. long) was found at Wiah Point, Queen Charlotte Islands, July 1955, under the tail of a "box-crab" (*Lopholithodes mandtii*) by Mr. T. H. Butler. It attracted attention by its brilliant luminescence on being touched. This character has not been noted previously. The species is best differentiated from *E. blomstrandi* Malmgren (the only other species with a complete ring of pharyngeal teeth known from western Canada) by the rounded ventral cirrus considerably shorter than the foot.

POLYNOIDAE
Lagisca multisetosa var. *papillata* Moore

Moore, 1908, p. 335.

An unusually large specimen (about 50 mm. long) of *Lagisca multisetosa* Moore dredged in Dixon Entrance in 180 to 198 metres by Mr. T. H. Butler has all the characters whereby the variety *papillata* is distinguished. It seems worthy of note since the variety has not been observed since it was originally recorded. It is not mentioned by Pettibone (1953) whose account of the species (as *Harmothoe*) is the latest and fullest to date.

ARICIIDAE
Scoloplos acmeceps Chamberlin

Chamberlin, 1919, p. 15.

This species has not been recorded previously from western Canada. It differs from the only representative of the genus known there, *Sc. armiger* (O. F.

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Müller), mainly in the absence of papillae ventral to the neuropodium in posterior thoracic and anterior abdominal setigers. It was collected littorally in 1952, at Stephens Island, Hecate Strait, by Dr. K. S. Ketchen and has also been found in a collection made by Dr. Fraser in the Queen Charlotte Islands in 1935.

PARAONIDAE

Aricidea *lopezi,* sp. n.

Four specimens dredged by Dr. R. I. Smith off Upright Head, Lopez Island in 21.6 metres, in mud, August 23, 1955. The specimens are very curled and difficult to measure. The longest is about 10 mm. in length and 0.5 mm. in width. Only one is complete posteriorly.

The prostomium is trilobed, the median lobe, rounded anteriorly, carries a tentacle narrow at the base, broader above, and tapering to a long thread-like tip. It reaches back to the fifth setiger. The lateral lobes show small eyes in one specimen (Fig. 1). There are 17 or 18 pairs of branchiae starting on the fourth setiger and increasing in length posteriorly until they are almost three times as long as the width of the dorsum. They are heavy at the base and have long tapering terminations (Fig. 2). The dorsal cirri are rather long in the branchial region and are thread-like in the posterior region. There are no ventral cirri. There are three anal cirri. Setae in the branchial region are all capillaries, the neurosetae with slender blades. In the post-branchial region the notosetae are very fine, fragile, capillaries and the neurosetae mostly heavy, long, knob-ended hooks with fine extensions (Fig. 3), accompanied by one or two very long capillaries.

The species comes near to A. *jeffreysii* (McIntosh), but differs markedly in the length and shape of the tentacle and branchiae and in the character of the posterior neurosetae. It differs from A. *heteroseta* Hartman (1948), to which it approximates in several particulars, by the length and shape of the tentacle and in the much smaller number of pairs of branchiae.

Aricidea (*Cirrophorus*) *branchiata* (Ehlers)

Ehlers, 1908, p. 124.

A number of specimens, dredged in 27 metres in mud in East Sound, Orcas Island, by Mr. R. A. Cloney of the University of Washington, agree with Ehlers' description of this species. This description was based on a specimen which lacked the posterior region. It measured 25 mm. for 71 setigers. The largest measured amongst the present specimens is complete, is about 12 mm. long, 0.5 mm. wide, and has more than 85 setigers. The posterior segments are very narrow and their dorsal cirri very slender, but they differ in no other particular from other postbranchial setigers. The body terminates in an anal ring with three cirri, two fine laterals and a shorter median ventral one.

Figure 4 illustrates the dorsal ramus of a postbranchial parapodium showing the heavy spine which characterises the sub-genus. The spine appears to be enveloped in a frail sheath.

The sub-genus *Cirrophorus* was originally set up by Ehlers as a genus of

Cirratulidae but later authors agree in making it a sub-genus of *Aricidea* (Paraonidae). *Cirrophorus branchiatus* is the type species. This was described from South Africa and remained a solitary observation until it was found last
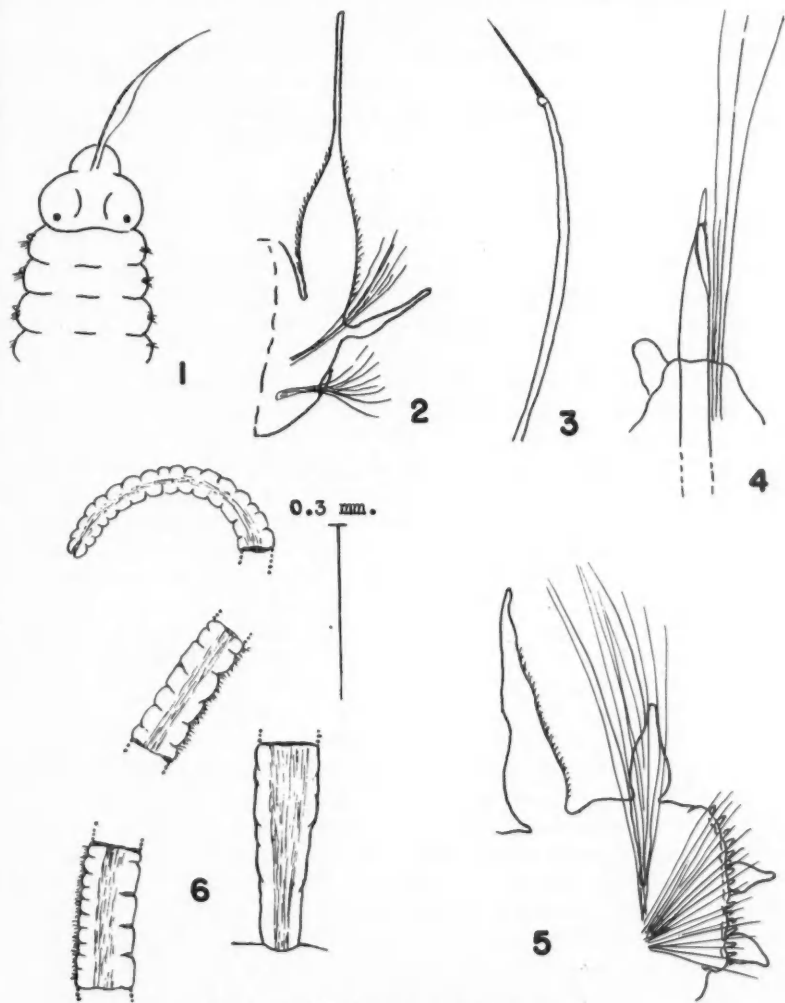
FIG. 1.—*Aricidea lopezi* sp. n. Anterior region.
FIG. 2.—*Aricidea lopezi* sp. n. Branchial setiger.
FIG. 3.—*Aricidea lopezi* sp. n. Neuroseta.
FIG. 4.—*Aricidea* (*Cirrophorus*) *branchiata* (Ehlers). Dorsal ramus of a postbranchial parapodium.
FIG. 5.—(?) *Nainereis quadricuspida* (Fabricius). Thoracic neuropodium.
FIG. 6.—*Cossura longocirrata* Webster and Benedict. Four regions of median cirrus.

year by Southward (1955) off the Isle of Man. These records, coupled with the present one, seem to suggest a very scattered distribution, but the animal is small and could easily be overlooked.

ARICIIDAE

(?) *Nainereis quadricuspida* (Fabricius)

ʀ'auvel, 1927, p. 23.

A single specimen collected littorally at False Bay, San Juan Island by L. Throckmorton is attributed to *Nainereis quadricuspida* with some doubt. It is 45 mm. long and about 1.5 mm. wide at the widest point, but lacks the anal end. It agrees in general with Fauvel's description, but has 26 to 27 thoracic setigers, instead of 12 to 17, and there are two papillae on the thoracic neuropodium (Fig. 5).

CIRRATULIDAE

Dodecaceria fewkesi (Fewkes)

Berkeley, E. and C., 1954, p. 326.

We wish to take this opportunity to correct a statement with regard to this species made in the paper quoted above and also in our 1952 publication. In both cases we refer to it as a littoral species. We overlooked references to its having been dredged in 18 metres off Santa Cruz Island, California, by Moore (1923). Recently too, a large rock heavily coated with colonies of the species was dredged off Goose Island, Hecate Strait, by Mr. W. E. Barraclough in 40 metres.

Cossura longocirrata Webster and Benedict

Webster and Benedict, 1887, p. 743; Eliason, 1920 p. 58; Wesenberg–Lund, 1950, p. 34.

This is another species new to western North America collected by Mr. R. A. Cloney in East Sound, Orcas Island. Several examples were taken near the mouth of the Sound in about 27 metres on a mud bottom with the Ekman dredge. A complete specimen is (as preserved) about 6 mm. long and 0.3 mm. wide and has about 65 segments, so far as can be made out in its coiled and twisted condition.

The genus *Cossura* was established by Webster and Benedict (1887) with the present species as type. The genus has remained monospecific. It is distinguished from other genera of *Cirratulidae* by the absence of lateral cirri (branchiae) and the presence of a long single median cirrus (branchia) on the fourth segment. The species is figured by Webster and Benedict with an achaetous segment posterior to the buccal segment. Neither Eliason nor Wesenberg-Lund were able to confirm this, both finding this segment setigerous, but they do not regard this as significant. We confirm their observation and share their opinion.

The characteristic single median cirrus (branchia) is, in the present specimen, 6 mm. long. It tapers very gradually, as it is figured by Webster and Benedict, but the constrictions, which are shown at the base in their figure, extend the whole length and are very irregular. Areas of ciliation can be detected on the cirrus and there appears to be a blood-vessel throughout. Evidently it is

very extensible, Wesenberg-Lund's figure (Pl. 8, fig. 36) showing it in a state of full contraction. In the present specimen it is almost completely extended and in the accompanying figure (Fig. 6) we show the condition in a series of four widely separated regions. The function is almost certainly branchial.

The anal segment terminates in three long cirri, as described by Webster and Benedict and there are three lobes between each pair of cirri. The setae are as described by Wesenberg-Lund and Eliason.

The species was originally described from Eastport, Maine; subsequently by Eliason and Wesenberg-Lund from northern Europe.

SPIONIDAE
Scolelepis fuliginosa (Claparède)
Fauvel, 1927, p. 25.

Two complete and two incomplete examples of this species were collected littorally by L. Throckmorton at False Bay, San Juan Island. The species is new to western North America and we have found no record of it from the east coast.

SABELLARIIDAE
Idanthyrsus armatus Kinberg
Berkeley, E. and C., 1952, p. 107.

The maximum length recorded for this species is 60 mm. (Pettibone, 1954; E. and C. Berkeley, 1952); more usually it is given as not more than 50 mm. It is interesting, therefore, to find that it can attain a very much larger size. A specimen recently dredged off Goose Island, Hecate Strait, B. C., in 40 metres, measured 95 mm. In all technical details it agreed exactly with the species.

Large tubes which, presumably, had been occupied by animals of this order of size are occasionally found in dredged material together with smaller ones, but in our experience they have invariably been empty.

SABELLIDAE
Euchone rosea Langerhans
Fauvel, 1927, p. 340; Southern, 1914, p. 146.

This species has been recorded once before from western North America, but with some doubt, since the specimens were taken from the stomach of a lemon sole (*Parophrys vetulus*) and were partially digested (E. and C. Berkeley, 1954).

Twelve specimens in good condition were collected by Mr. R. A. Cloney in East Sound, Orcas Island, in 27 metres on a muddy bottom. They agree very closely with Southern's (1914) description and their record removes the doubt attached to the previous one from the coast. The average length of five specimens (without branchial plume) is about 4 mm.

SERPULIDAE
Spirorbis validus Verrill
Pixell, 1912, p. 800.

This species has not been taken in western Canada since it was originally recorded there by Pixell. Good specimens were present in material collected

littorally at Virago Sound, Queen Charlotte Islands, by Mr. T. H. Butler in September 1955. The structure of the operculum is characteristic. When fully mature this develops an anterior and a posterior calcareous plate between which the eggs are incubated. Another plate is then developed posteriorly and the original posterior one becomes the anterior plate of a second brood pouch, and this process may be repeated. A succession of plates is thus built up, two or more of which may remain attached. The figure given by us (1952), taken from Bush (1904), is a somewhat inadequate representation of one of these plates. A similar arrangement is described and figured by Fauvel (1927, p. 401) for *Spirorbis koehleri* Caullery and Mesnil.

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The Effect of Fry Plantings on Whitefish Production in Eastern Lake Ontario[1]

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ABSTRACT

Whitefish fry were planted in the Bay of Quinte and adjacent waters in numbers varying from 208 millions in 1927 to none in 1945. Since 50% of the commercial whitefish catch from these waters consisted of five-year-old fish, whitefish production in each of the years from 1929 to 1951 was compared to the number of fry planted 5 years previously (1924–1946). No correlation could be found between the number of fry planted and the production of whitefish 5 years later. The largest number of fry planted (208 millions in 1927) was followed by the lowest production of the entire period (95 thousand pounds in 1932). On the other hand, following no planting in 1945, production in 1950 was approximately normal (162 thousand pounds).

The age composition of the commercial catch in the years 1944–1951 was determined from scale samples. By applying the age composition to the total catches in these years the contributions of the year-classes 1940–1945 have been estimated. The number of fry planted probably did not affect the contribution of these year-classes to the fishery.

INTRODUCTION

THE planting of fry of commercial species of fish in the Great Lakes and other large lakes has been standard practice for over 50 years. These fry have been planted in the expectation that they would increase the abundance and ultimately the production of fish of commercial size. Since the early 1930's several investigations have been made to determine the effectiveness of this maintenance planting practice.

Hile (1937) after an extensive analysis of the fishery for pike-perch, *Stizostedion vitreum* (Mitchill) in Lake Huron could find no correlation between the number of fry planted and the abundance in subsequent years. Van Oosten (1942) could find no causal relationship between the plantings of whitefish fry and the catch in subsequent years in Lake Erie. Carlander (1945) in his studies of the pike-perch with special reference to the commercial fisheries in the Lake of the Woods, Minnesota, could not demonstrate any correlation between abundance and the number of fry planted. Miller (1946) demonstrated that whitefish year-classes supported by plantings of eyed eggs were often weaker than the unsupported year-classes. In his study plantings were made in alternate years in six Alberta lakes and an analysis of the age composition of the catches in

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subsequent years revealed no additional strength in the year-classes supported by planting.

An investigation similar to Miller's has been under way in the Bay of Quinte area of Lake Ontario since 1944. The aim of this investigation is to determine the relative effectiveness of hatchery culture of whitefish, *Coregonus clupeaformis,* as compared with natural reproduction in maintaining the population at a desirably high level. Towards this end the Glenora whitefish hatchery which supplies the Bay of Quinte has hatched whitefish for planting in that area only in the even-numbered years since 1944. Thus, in the years 1945, 1947, 1949, 1951 there have been no plantings of whitefish fry in the Bay of Quinte area. If these naturally reproduced year-classes have suffered from this lack of support their contributions to the commercial catch in subsequent years should show evidence of it.

PAST WHITEFISH PRODUCTION IN LAKE ONTARIO

Whitefish production in the Canadian waters of Lake Ontario has fluctuated considerably during the period (1867–1951) for which records are available. Since records of whitefish production in the Canadian waters of Lake Ontario are available for a longer period of time than those of the entire lake, they have been used in this paper. They should describe the trends of production for the whole lake because 90% of the whitefish production of Lake Ontario has been from Canadian waters. These trends are shown in Figure 1.

The International Board of Inquiry for the Great Lakes Fisheries (1943) had divided the period 1867–1940 into six smaller periods on the basis of production and has arbitrarily chosen the period 1867–1881 with an average annual catch of 700,000 pounds to represent what may be called "normal production". In the succeeding period (1882–1893) production decreased to 50% of "normal"
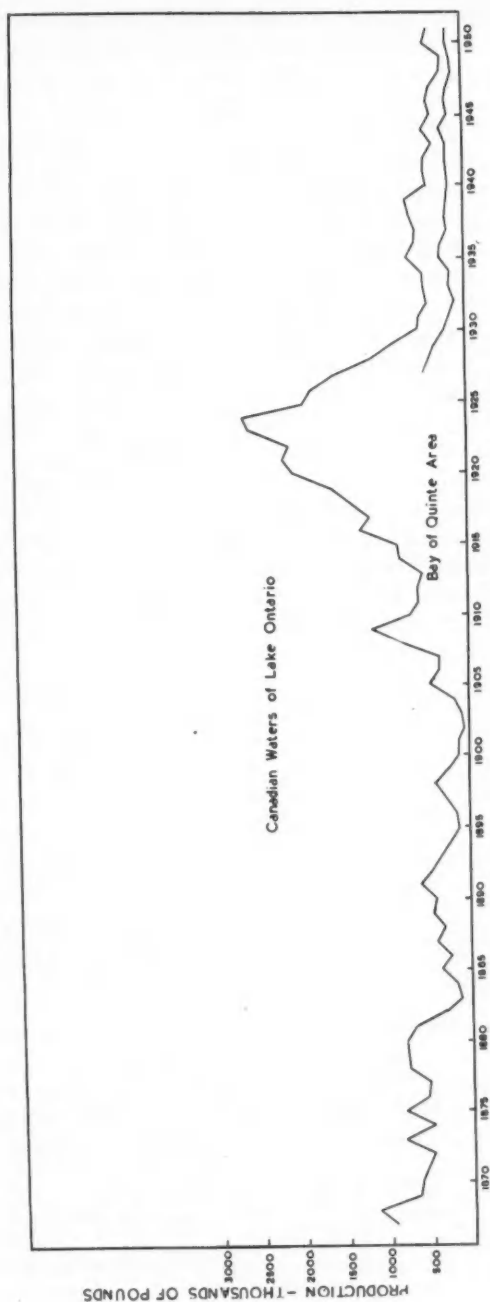
Fig. 1.–Production of whitefish in the Canadian waters of Lake Ontario.

and further decreased in the period 1894–1904 to less than 200,000 pounds (27% of "normal"). After a preliminary increase to near "normal" (91%) in the years 1905–1915 whitefish production rapidly increased to reach a peak of 2,652,000 pounds in 1924, the average annual production in this period (1916–1928) being 1,704,000 pounds. Following the peak in 1924 there was a steady decline to 1930. A relatively stable level of production then began and has continued to the present time with an average annual production of 453,000 pounds.

On the basis that normal production is 700,000 pounds the fishery has been operating at approximately 65% of normal for the past 20 years. It should be remembered, however, that the use of the "normal period" is merely one to facilitate a description of production trends. It need bear no relation to sustained yield: an appraisal of the trends demonstrated by Figure 1 raises the doubt that such a condition as "normal" exists or that sustained yield with a narrow range of fluctuation is possible.

THE BAY OF QUINTE FISHERY

The Bay of Quinte area (Fig. 2) as referred to in this paper consists of the Bay of Quinte proper and the Canadian waters of Lake Ontario off Prince Edward County. The whitefish fishery is the most valuable for the commercial fishermen in this area although in the past 6 years it has been exceeded in production by the trapnet fishery for bullheads (*Ameiurus nebulosus*). A fairly extensive smelt (*Osmerus mordax*) fishery has also been developed in these waters in the past ten years.
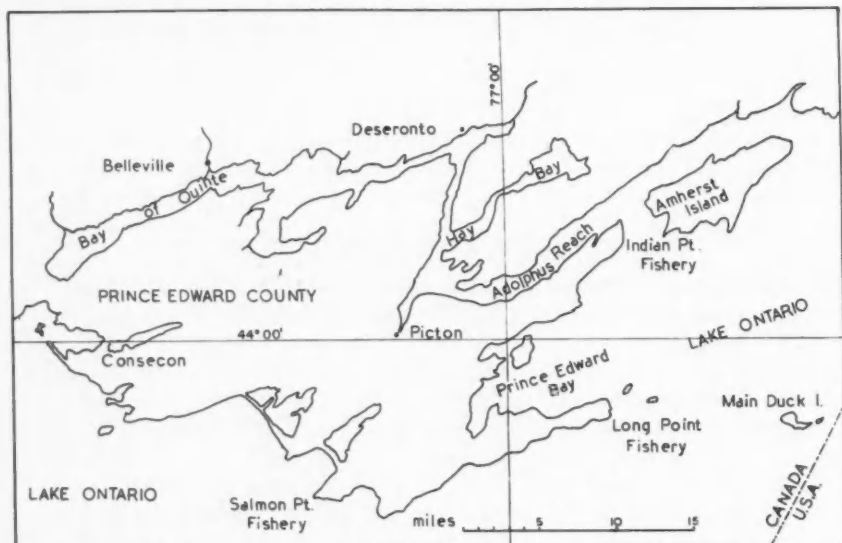
Fig. 2.—Location of the Bay of Quinte fishery. (The place names given are the ones in common local use.)

Between 15 and 20 gillnet boats normally exploited the whitefish population of this area during the period of the investigation. The main fisheries are those off Long Point and Indian Point with smaller operations being carried out from Salmon Point and Consecon. In the late fall the main fishing effort is concentrated in Adolphus Reach and the Bay of Quinte proper. At this time the farmers fishing small yardages of net are active as well as the regular fishing fleet.

The fishery for whitefish is a highly selective one in which only gill-nets are used. The mesh size must not be smaller than 4½ inches (stretched measure).

There is little definite knowledge of whitefish migrations in Lake Ontario but the observations of fishermen provide certain information. According to local fishermen fishing is better off Long Point (see Fig. 2) during June and July and off Indian Point during August and September. They believe that the white-fish move gradually from Long Point north through Prince Edward Bay to the Indian Point region during these months. During September they are concentrated in Adolphus Reach and off Indian Point and in October move gradually westward to the spawning grounds located between Glenora and Trenton.

METHODS

Practically all the fish caught in the Bay of Quinte and adjacent waters are handled by a single dealer located at Picton, Prince Edward County. An investigator has been stationed at this establishment during the months June–September since 1944. Through the cooperation of this company he has been able to examine various whitefish catches before they were packed for market.

The investigator accompanied the warehouse truck on its route to collect the various catches and thus determine the origin of these catches. On return to the warehouse the catch from each boat was kept separate and examined. Each fish was measured from the tip of the nose to the fork of the tail to the last quarter-inch contained within this distance. In addition, total lengths were obtained by compressing the lobes of the caudal fin together and measuring similarly. Fork lengths are used in what follows, except as noted; fork length = 0.906 total length. Individual fish were weighed in pounds and ounces. Scale samples were removed from the area above the lateral line and immediately anterior to the origin of the dorsal fin on the left side of the fish. At a later date, the scale samples were impressed on cellulose acetate slides and the impressions magnified and projected on a screen. The number of annuli were then counted and the age recorded as the number of completed annuli in the scale.

A total of 14,358 fish from 484 different catches was examined in the above manner in the years 1944–1951. Except for a hmall percentage of regenerated scales the ages of all fish examined in the years 1944 through 1949 have been determined. Every third scale sample taken in 1950 and 1951 was read.

LENGTH DISTRIBUTION OF THE CATCH

The restriction of the gill net fishery to 4½ inch mesh necessarily makes it highly selective. Some variation exists among the length distributions of the various years but in 6 of the 8 years either the 16.5- or 17.0-inch group has been

the mode. During the 8-year period 35% of the catch has been in the size range 16.5–17.5 inches and 75% of the catch has consisted of fish between 15.5 and 18.0 inches in length. The largest whitefish examined measured 24.5 inches in length and the smallest 10.0 inches.

LENGTH–WEIGHT RELATIONSHIP

The majority of the whitefish taken in the Bay of Quinte area have weighed between 1¾ and 3 pounds round weight, and only a small percentage have exceeded 4 pounds. Owing to the selectivity of the gear the length–weight curve in Figure 3 represents only the commercial catch and not the true relationship.
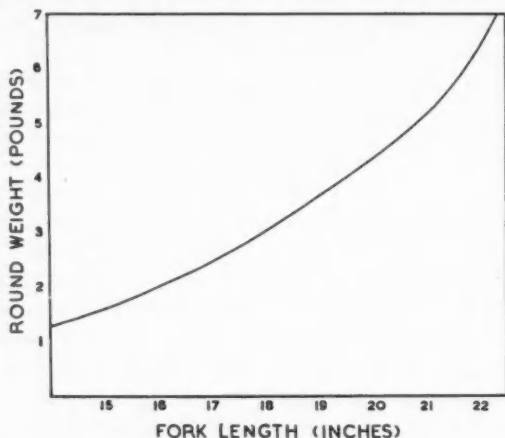
Fig. 3.—Length–weight relationship of the whitefish landed in the commercial catch.

Mesh size selects fish more on the basis of weight than on length and in the lower length groups more of the heavier fish would be caught. Similarly the lighter fish of the higher length-groups would be selected, thus resulting in a flattening out of the length–weight curve. Net selection is at a minimum in the 16–18-inch fork-length range and the average weights of 2, 2½, and 3 pounds at lengths of 16, 17, and 18 inches, respectively, are probably near the true value. At this size Bay of Quinte whitefish gain ½ pound in weight for each inch of increase in length.

AGE COMPOSITION OF THE COMMERCIAL CATCH

The percentage age compositions of the samples collected in the years 1944–1951 are entered in Table I. The roman numerals by which the age groups are designated represent the number of complete annuli. Age group V was the main support to the fishery, its contributions ranging from 38% to 60% of the annual catch and averaging 47% for the 8-year period. Age group IV was the next highest contributor with 22% and was closely followed by age group VI

TABLE I.—Percentage age composition of whitefish removed from the Bay of Quinte area in the years 1944–1951. Estimates for 1944 through 1947 from data of E. J. Hamley.

Year of Capture	Age in years completed									
	III	IV	V	VI	VIII	VIII	IX	X	XI	XII
1944	0.3	15.0	42.6	25.8	11.5	3.1	1.3	0.2	0.1	0.1
1945	1.8	20.4	46.6	20.9	6.5	3.1	0.5	0.1		
1946	1.3	27.4	37.7	27.1	5.3	0.7	0.3	0.1	0.1	
1947	0.6	20.0	38.7	25.4	11.4	2.7	0.7	0.4	0.1	0.1
1948	0.7	17.2	47.0	24.0	8.0	2.5	0.6	0.07		
1949	1.5	15.1	59.4	18.5	4.5	0.8	0.2			
1950	0.4	32.0	47.2	13.0	6.2	1.1	0.3			
1951	0.9	28.0	59.1	6.9	3.1	0.8	0.3	0.4		
Mean	0.9	21.8	47.3	20.2	7.1	1.8	0.5	0.2	0.1	0.1

with 20%. Eighty-nine per cent of the fishery over this 8-year period has consisted of age IV, V and VI whitefish. The percentage composition has varied only slightly during this period. Age group V has easily maintained dominance, while in certain years age group VI has supplanted age group IV for second place. Only 2% of the catch was age VIII and older and the highest age determined was age XII.

AGE–LENGTH RELATIONSHIP

Owing to the selectivity of the gear used the age–length data do not describe the true growth rate. The age–length relationship of the commercial whitefish catch as determined for 1944–47 and 1948–51 is shown in Figure 4, as is also the growth of Lake Ontario whitefish as determined by Hart (1931). Hart's measurements were of standard length and were converted to total length by Van Oosten and Hile (1949). Their conversions have been converted to fork lengths for use in this comparison.
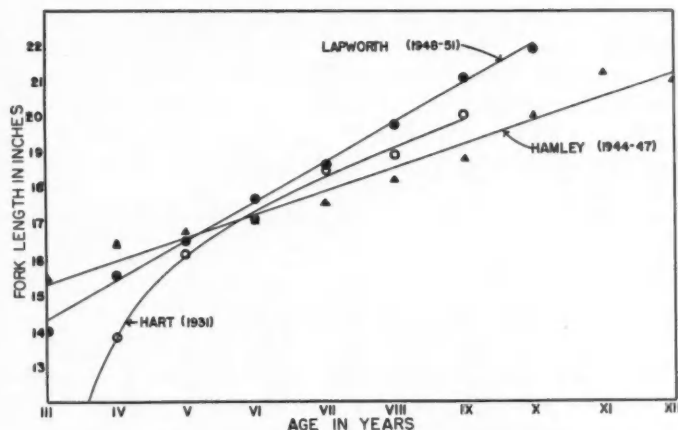
FIG. 4.–Age–length relationship of whitefish in the commercial catch.

The difference between Hart's curve which was based on fish taken in a string of experimental gillnets of various sizes and the age–length curves of the commercial catch reflects the selectivity of the 4½-inch mesh gill-net indicating that only the larger members of the younger ages are taken. Apparently, however, this gear takes a representative sample of age groups V, VI and VII since the age–length relationship at these ages is nearly the same in all three curves. The reason for the difference between the age–length relationship obtained by Hamley and by Lapworth has not yet been determined but it is probably due to differences in scale reading techniques.

Van Oosten and Hile (1949) have compared the growth of whitefish in Lake Ontario (Hart), Lake Erie and Lake Huron and found that whitefish growth is considerably slower in Lake Ontario than in the other two lakes. In their comparison, Lake Ontario whitefish were not as long in their ninth year as were Lake Erie whitefish at the end of their seventh or Lake Huron whitefish at the end of their sixth year. The present data support their conclusions.

PLANTING OF WHITEFISH FRY

Whitefish fry have been planted in the Bay of Quinte area in varying numbers since 1882. The numbers of fry planted in each year from 1924 to 1947 are plotted on the graph in Figure 5. The average planting during this period was 83,000,000 fry per year. The largest planting was that of 208,000,000 fry in 1927 while in 1945 no fry were planted.

If these plantings were appreciably affecting the fishery it is reasonable to assume that a large planting would result in a higher production than would a
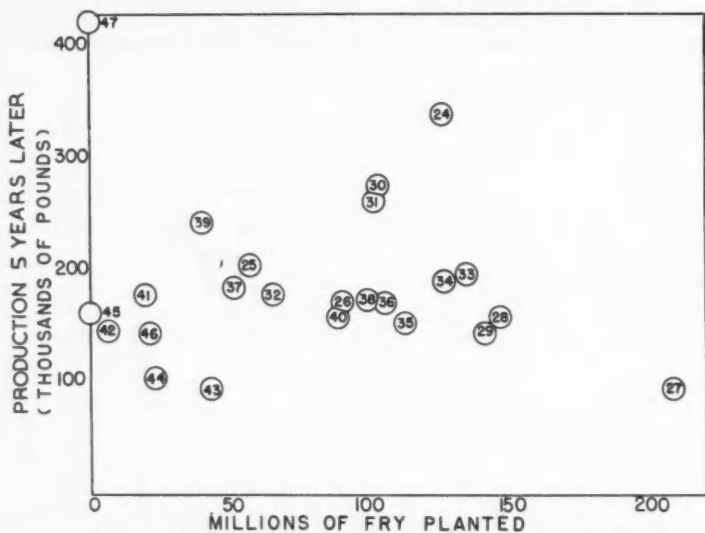
Fig. 5.—Relation between number of whitefish fry planted and the commercial catch in the Bay of Quinte fishery five years later.

smaller one. Since on the average 47% of the whitefish taken in the Bay of Quinte area are of age V it would be expected that the production 5 years after planting would show the greatest effect of this planting. On this assumption, the fry plantings during this period have been plotted according to their magnitude, in Figure 5, at the corresponding level of production 5 years later. These points should rise from left to right if planting is effective. That is, small plantings should be followed by small productions, and large plantings by large productions. No such trend is evident. The greatest number of fry planted was 208,000,000 in 1927. If this planting had been beneficial the catch in 1932 should have been well above average. Instead the 1932 catch was the lowest taken in the entire period. In contrast, when no planting was made in 1945 the catch 5 years later was only slightly below normal. The production 5 years after 1947, another year in which no planting was carried out, was the highest over the whole period. Similar comparisons between plantings and the production 4 years later and 6 years later have also failed to show any correlation.

YEAR-CLASS STRENGTH

The numbers of fish of each age group caught in the years 1944–1951 have been calculated from the production poundage by use of the average weight of the various age groups. For example, 105,097 pounds of whitefish were landed from the Bay of Quinte in 1949. The average weight of the whitefish examined in this year was 2.4 pounds. The number of fish caught in 1949 was therefore estimated to be $105,097/2.4 = 43,800$. By applying the percentage age composition of the 1949 catch (see Table I) to the number of fish caught (43,800) the number of fish of each age group taken in 1949 has been determined.

The numbers of fish of various ages taken in the years 1944–1951 have been determined in the above manner and are entered in Table II. In this table the progress of several year-classes through the fishery can be traced. The year-class hatched in 1941, for example, entered the fishery at age III in 1944 by contributing 300 fish. Reading diagonally, in 1945 at age IV it contributed 13,845 fish; in 1946 at age V, 29,105; etc., until it had finally passed through the fishery. By adding this diagonal column a minimum estimate of the 1941 year-class upon entering the fishery is found to be 62,630 fish. Similarly by adding the other diagonal columns in Table II the contributions of various year-classes have been deter-

TABLE II.—Estimated numbers of whitefish of various age groups taken by the commercial fishery in the Bay of Quinte in the years 1944–51.

Year of Capture	Age Group										TOTAL
	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
1944	300	15105	42900	25980	11580	3125	1310	200	100	100	100700
1945	1220	13845	31630	14180	4415	2100	340	70			67800
1946	1005	21150	29105	20920	4090	540	230	80	80		77200
1947	370	12250	23700	15550	6980	1655	430	245	60	60	61300
1948	240	6400	17500	9000	3000	920	215	25			37300
1949	660	6560	26100	8100	1950	365	65				43800
1950	260	21450	31700	8745	4160	710	175				67200
1951	660	20110	42490	5050	2230	590	190	290			71600

mined (Table III). The year-classes 1940–1945 have been exposed to the fishery long enough to compare their contributions to the fishery, since 90% of the fishery consists of age IV, V and VI fish. Therefore these year-classes up to 1945 have made their major contributions to the fishery and a reasonable comparison can be made.

TABLE III.—Catch of whitefish taken from successive year-classes, and the number of hatchery fry planted. (Year-classes 1944 and 1945 will contribute some thousands more to the fishery.)

Year-class	Catch (thousands of fish)	Fry planted (millions)
1940	75.6	89
1941	62.6	20
1942	57.9	5.5
1943	43.6	43
1944	43.8+	23
1945	43.6+	0

The fishery removed approximately 75,620 fish from the 1940 year-class and the 1941 year-class ranked second with a contribution of 62,630 fish. The year-classes 1942, 1943, 1944 and 1945 appear to have been of almost equal strength, their contributions varying between 57,920 (1942) and 43,550 (1945). The 1944 and 1945 year-classes will probably contribute several thousand more fish before they pass completely through the fishery.

YEAR-CLASS SUPPORT BY PLANTINGS

It has already been demonstrated (Fig. 5) that no correlation exists between the number of fry planted and the production of whitefish 5 years later when such support would be expected to express itself. A more direct method of determining whether a correlation exists between planting and production is to compare the contributions of each year-class to the fishery with the planting support they have received (Table III).

Although the 1940 year-class which had the largest planting (89 million fry) gave the highest production these data appear to show no better correlation between planting effort and year-class strength than was displayed in Figure 5. The 1941 year-class which was second in production was supported by only 20 million fry. The contribution of the four year-classes 1942–45 were essentially all the same and these resulted from plantings varying from zero to 43 million fry.

When the year-classes of 1947, 1948 and 1949, which are being exploited at the present time, have passed through the fishery and their contributions determined, a more thorough understanding of the value of maintenance plantings will be had. However, from the data on hand the only conclusion permitted is that whitefish fry plantings in the Bay of Quinte area have been of little value in increasing whitefish production.

MAXIMUM RATE OF EXPLOITATION

Estimates of the rate of fishing mortality of the Bay of Quinte whitefish population cannot yet be made but an upper limit can be placed on such exploitation as pointed out by Fry (1949). This is done by assuming that all whitefish which enter the fishery are destined to be captured (no mortality from natural causes).

If 100 fish enter the fishery at age III then according to the percentage age composition (see Table I) 0.8 are taken in that year leaving 99.2 survivors. At age IV 20.9 are taken, 78.3 surviving to age V at which age 42.4 are taken, etc., until at age XII the original 100 fish have been removed. Now at age IV 21.9 out of 99.1 were killed representing a reduction of 22%; similarly at age V there was a reduction of 61%, at age VI 68%, etc. In this manner a maximum estimate of the rate of exploitation has been made by assuming natural mortality to be zero.

It can be seen from Figure 6 that the exploitation steadily increases from the time whitefish enter the fishery until their sixth year and after this age the maximum estimate of exploitation is more or less constant at 70%. Exploitation of age III is of course very small because most of the fish of this age are too small to be caught by the gear used.

The major limitation to the exploitation curve in Figure 6 is that it takes no account of natural mortality after the fish have entered the fishery but the exploitation curve gives maximum estimates of the exploitation to which the Bay of Quinte whitefish population was exposed.
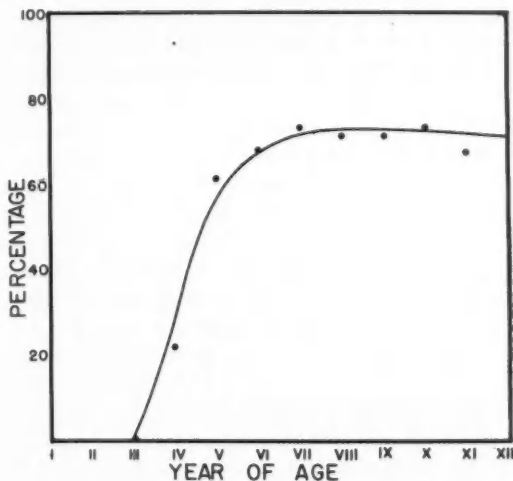
Fig. 6.—Maximum estimates of the percentage rate of exploitation of the Bay of Quinte whitefish populations, at successive ages.

CONCLUSIONS

1. While the investigation is still in progress and more definite conclusions will be available when the results of the planting in alternate years are complete, the data on hand indicate plantings have been of little value in increasing whitefish production in the Bay of Quinte area.

2. Maximum estimates of exploitation indicate that the whitefish in the Prince Edward region of Ontario are free of exploitation until year IV. The level of exploitation is relatively high after year VI.

3. Year-class production of whitefish in the Bay of Quinte over the years 1940–1945 varied less than twofold.

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Chemical Changes in Nitrite-Treated Atlantic Cod Fillets in Relation to Spoilage Assessment[1]

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ABSTRACT

Results are reported from preliminary studies using various analytical methods to detect spoilage in nitrite-treated Atlantic cod. In a more intensive study of one method, it was found that fresh fillets could be separated from spoiling fillets by their gains in tyrosine value after 3-hour incubation at room temperature.

INTRODUCTION

FRESH Atlantic cod fillets marketed in Canada generally contain up to 200 p.p.m. sodium nitrite as a preservative. Sodium nitrite suppresses the formation of trimethylamine (Castell, 1949a; Dyer, 1949), the measurement of which has been shown to be one of the more useful objective tests for the detection of bacterial spoilage in cod and haddock (Beatty and Gibbons, 1937; Dyer and Dyer, 1949; Castell and Triggs, 1955). Accordingly, the main object of this research has been to seek a convenient method for the routine measurement of spoilage in nitrite-treated cod fillets on the Canadian retail market.

Nitrite added to fish is reduced by bacterial action (Dyer and Castell, 1949). The bacteria responsible in chilled fish belong largely to the genera *Pseudomonas* and *Achromobacter* (Castell, 1949b). Since these genera also play an important part in fish deterioration by producing spoilage odours (Castell and Anderson, 1948; Castell and Mapplebeck, 1952) it was thought that the rate of disappearance of nitrite might be correlated with the degree of spoilage. This hypothesis was tested where nitrite disappearance rates were estimated after 3-hour incubation periods at room temperature. A similar incubation technique was used by Hess (1941) to increase the usefulness of trimethylamine as a spoilage index. Also, Tarr (1943) suggested that the increase in numbers of bacteria on fish after 24-hour incubation at 15°C. was related to the potential keeping quality of the fish.

It was thought desirable also to seek biochemical changes which could be correlated with the progress of spoilage in nitrite-treated fillets. The literature on post-mortem chemical changes in fish has been reviewed recently by Sigurdsson (1947), Reay and Shewan (1949), and Tarr (1954).

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METHODS

PREPARATION OF FISH SAMPLES

All the cod used were filleted commercially and were reputedly less than one day old when obtained. To minimize errors in sampling and to assess better the differences due to treatment, certain of the analyses were made on a fish homogenate. In preparing this homogenate, a number of cod fillets were minced, thoroughly mixed, and weighed into portions. To each portion was added in equal amounts (w/v) either water or a sodium nitrite solution. Each preparation was then blended in a Waring blendor, dispensed in about 45-g. amounts into several petri plates, and stored at 3°C. Analyses as described later in this section were made periodically on samples, usually weighing 10 g., immediately after preparation and sometimes again after 3-hour incubation at room temperature.

Tyrosine value determinations were also made on a number of whole cod fillets that had been dipped in nitrite commercially. The fillets were wrapped individually in waxed brown paper and stored at 3°C. To minimize errors in sampling due to the size of the fillet (Wood et al., 1942) only the outside 5 mm. was analyzed. A strip of this thickness was cut conveniently from the fillet with the aid of a fixture which was essentially a rectangular wooden tray having slots along both its long sides 5 mm. from the bottom of the tray. These slots served to guide a sharp wet knife through the fillet. During the cutting operation the fillet was pressed down to the bottom of the tray with a loose-fitting wooden cover. The strip of fish was then weighed (about 50 g.) and blended with four times its weight of water. Ten ml. of this homogenate was analyzed immediately and 10 ml. was set aside for analysis after 3 hours.

Once the fish arrived at the laboratory, care was taken to avoid grossly contaminating them with bacteria from the hands and equipment. All experiments were performed on at least two lots of fish purchased at different times; however, since the results were similar, in most cases only one experiment is reported.

SPOILAGE ASSESSMENT

Just prior to analysis the fish were examined for spoilage odours. Fish were considered spoiled as soon as they acquired an odour intensity associated with that of a nitrite-free fish containing about 15 mg. of trimethylamine nitrogen per 100 g. of fish. Whenever possible, confirmation of decisions based on such organoleptic examinations was obtained from other trained personnel.

ANALYTICAL METHODS

Sodium nitrite was determined on water extracts by the method of Dyer (1946).

Tyrosine was determined on filtered 5% trichloroacetic acid extracts by the method of Wood et al. (1942).

Volatile acids were determined by Sigurdsson's modification (1947) of the method of Friedeman (1938).

Trimethylamine was determined on 5% trichloroacetic acid extracts by the method of Dyer (1945).

Amino acids were determined after slightly modifying the colorimetric method described by Spies and Chambers (1951) as it was considered desirable

to determine the optical density on protein-free solutions because the low ratio of free amino acid to protein in fish resulted in extremely cloudy solutions. Furthermore, use of the method in conjunction with chromatography was anticipated. The following extraction procedure resulted in clear solutions and recovered 99% of the alanine added to fish:

Fish plus an equal weight of water were blended for 2 minutes. An aliquot of the blend was shaken occasionally with an equal amount of 5% trichloroacetic acid during 15 minutes, then filtered. An aliquot of filtrate was carefully neutralized with sodium hydroxide solution to the thymol blue end point, made to volume, and analyzed for amino acid content.

Ammonia was diffused by the method described by Conway and Byrne (1933), and nesslerized as suggested by these authors. The nesslerization procedure was that recommended for the photo-electric colorimeter by Hawk *et al.* (1954). Nessler's reagent was prepared according to Koch and McMeekin (1924). Experiments showed that trimethylamine, in concentrations expected in cod, does not react with Nessler's reagent.

RESULTS AND DISCUSSION

BIOCHEMICAL CHANGES IN COD HOMOGENATES

It should be pointed out that the sodium nitrite concentration in fish treated commercially with this preservative may vary from practically zero to the 200 p.p.m. permitted by law. These variations result because the fish are dipped in a sodium nitrite solution and the amount absorbed by the fish depends on factors such as their size, the time they remain in the solution, and the regularity with which the nitrite solution is changed or strengthened. Because keeping quality is proportional to the initial nitrite concentration (Dyer and Castell, 1949), any useful spoilage test must necessarily indicate spoilage over the whole range of permissible nitrite concentrations. This prerequisite simplified the search for a suitable objective index for spoilage in that it was sufficient to compare the spoilage pattern of a cod homogenate containing no nitrite with one containing 200 p.p.m. It would also seem that the relation between the spoilage of a homogenate and of a fillet is sufficiently close to justify the use of the former in preliminary experiments of the type reported. This was ascertained by comparing the pattern of the curves obtained for the disappearance of nitrite during storage (Fig. 1) and the inhibition of trimethylamine by nitrite (Fig. 4) with those obtained by Dyer and Castell (1949) for whole cod fillets.

The results shown in Fig. 4 confirm the work of Dyer (1949) and Castell (1949a) in showing that trimethylamine cannot be used as a spoilage index in nitrite-treated fish. The homogenate containing no sodium nitrite spoiled at a trimethylamine level of 10 and that containing 200 p.p.m. at 2.4. Neither can ammonia (Fig. 5) be so used; in this case the nitrite-treated homogenate contained the greater amount of ammonia. The data suggest that ammonia should contribute more to the spoilage odours of nitrite-treated fish than to those containing no nitrite. This difference was not noticed organoleptically.
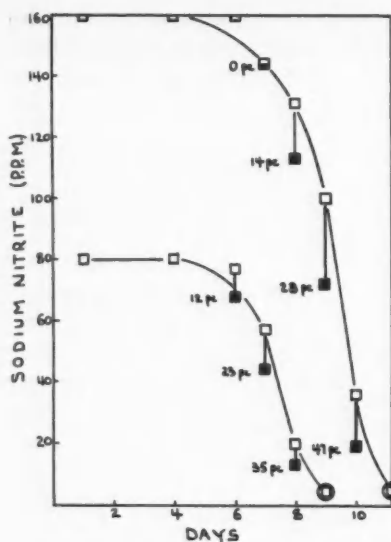
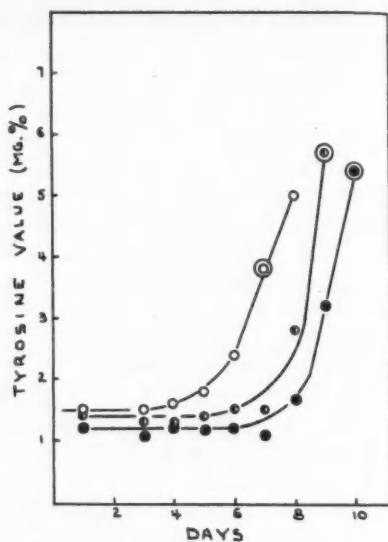FIG. 1.—Sodium nitrite content of cod homogenate stored at 3°C.

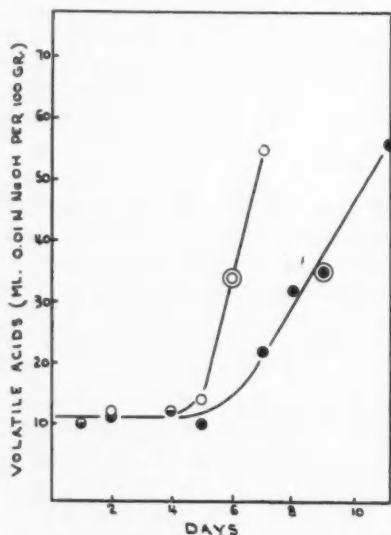FIG. 2.—Tyrosine value of cod homogenate stored at 3°C.

FIG. 3.—Volatile acid content of cod homogenate stored at 3°C.

Legend for Fig. 1–3

□—Before incubation.

■—After 3-hour incubation.

pc—Percentage decrease after incubation.

○—No sodium nitrite.

◐—100 p.p.m. sodium nitrite.

●—200 p.p.m. sodium nitrite.

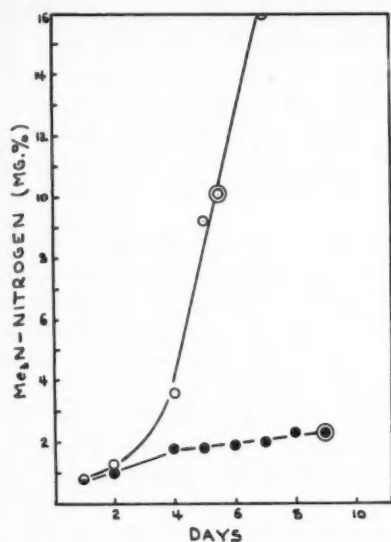⊙—Approximate time homogenate spoiled.
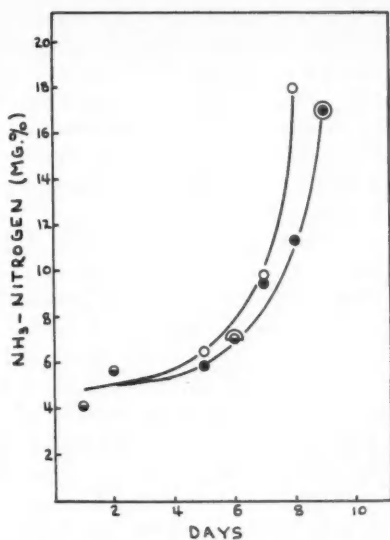
Fig. 4.—Trimethylamine content of cod homogenate stored at 3°C.

Fig. 5.—Ammonia content of cod homogenate stored at 3°C.

Fig. 6.—Amino acid content of cod homogenate stored at 3°C.

Legend for Fig. 4–6

○—No sodium nitrite.

●—200 p.p.m. sodium nitrite.

◉—Approximate time homogenate spoiled.

The amino acid content of the homogenate (Fig. 6) was too irregular to be used as a spoilage index. The data are of interest because the sharp upswing in amino acid content at 7 days indicates that protein breakdown was negligible until that time. This interpretation is substantiated because the analytical method, which detects tripeptides *qualitatively*, showed that these first occurred at 8 days' storage of both samples. Furthermore, it would seem from the data that the action of nitrite in preserving fish can only be slightly connected with its ability to inhibit proteolysis.

The volatile acid content of the homogenate (Fig. 3) might be a useful spoilage index, as both the treated and untreated homogenates spoiled when the volatile acids reached similar levels. The results in Fig. 2 indicated that the differences in tyrosine values at the spoiled state in homogenates containing no sodium nitrite (3.8 mg.%), containing 100 p.p.m. (5.7 mg.%), and containing 200 p.p.m. (5.4 mg.%), were not too great to render their use impractical as a spoilage index. The gradual increase in tyrosine value before spoilage, particularly in the untreated fish, suggests that it might be more useful than volatile acids in detecting intermediate stages of spoilage. The simplicity and speed of determining tyrosine values makes it extremely well suited for routine analysis, whereas volatile acids are determined by a time-consuming distillation technique. For these reasons, it was decided to investigate further tyrosine values as a spoilage index.

It should be pointed out that "tyrosine value" is a term of convenience rather than fact, for besides tyrosine, the method described measures other phenols, tryptophan, cystine, hydrogen sulphide, trimethylamine, and other reducing agents (Bradley and Bailey, 1940; Dyer, 1945). It is apparent from comparing the curves for amino acids (Fig. 6) and for tyrosine values (Fig. 2) prior to spoilage, that the two at best are inversely related. Thus any merit which the "tyrosine value" may have as a spoilage index, particularly in untreated cod, is not due to its ability to detect amino acids. However, this is probably not the case when fish containing near the maximum legal concentration of sodium nitrite are approaching the end of their keeping time.

TYROSINE VALUE OF COD FILLETS

When tyrosine values were applied to estimating spoilage in whole cod fillets, it soon became apparent that the values among individual fillets with similar histories were too widely scattered to be of much use as a spoilage index. Tarr and Bailey (1939) reported a similar occurrence with halibut. However, when measurements were made before and after 3-hour incubation at room temperature, it was found that the standard deviation of the gains in tyrosine were a great deal smaller and thus were probably independent of the initial value.

Table I shows the results of applying the incubation technique to groups of nitrite-treated cod fillets bought from different fish plants. The data from each group of fish were kept separate because random sampling indicated that the nitrite content between groups differed considerably. Tyrosine values were measured only until the fish reached the borderline of spoilage, which was considered to occur one day prior to actual spoilage.

TABLE I.—Tyrosine values of whole cod fillets before and after 3-hour incubation at room temperature.

Code letter	Days stored	No. of fish tested	Sodium nitrite	Initial tyrosine		Gain tyrosine	
				Mean	Standard deviation	Mean	Standard deviation
			p.p.m.	mg. %		mg. %	
A	0	5	25 to 50	2.9	...	0.12	0.06
B	1	7	"	2.6	...	0.21	0.11
C	2	7	"	2.7	...	0.44	0.22
D	3	8	"	3.8	1.11	0.66	0.13
E	4	8	"	4.4	1.77	1.19	0.30
F	1	5	75 to 120	2.8	0.51	0.12	0.08
G	2	5	"	4.2	1.80	0.09	0.08
H	3	8	"	3.0	0.47	0.14	0.09
I	4	3	"	4.8	...	0.17	...
J	5	7	"	3.7	0.94	0.80	0.28
K	6	10	"	4.2	0.97	0.96	0.27

An analysis of variance showed there were highly significant differences between the gains in tyrosine value of the following groups of fish (see Table I for code):

$$(A + B) \; vs. \; D$$
$$(F + G) \; vs. \; J$$
$$(A + B + F + G) \; vs. \; (D + J)$$

Since the fillets in groups D and J also possessed the first faint spoilage odours, it would seem that gains in tyrosine value could be used to separate the fillets into at least two quality classes. It is suggested that for practical purposes the distinction between fresh fillets and spoiling fillets be made at a gain in tyrosine value of 0.6 mg.%. In this experiment, about 3% of the fillets judged as fresh had gains in tyrosine value greater than 0.6 mg.% and 3% of those judged as spoiling had gains less than 0.6 mg.%.

DISAPPEARANCE OF SODIUM NITRITE

Figure 1 illustrates the relationship between the decrease of sodium nitrite from initial concentrations of 80 and 160 p.p.m. and the time required for the cod homogenates to spoil when stored at 3°C. It is apparent from Fig. 1 that the percentage reduction of nitrite after 3-hour incubation indicates fairly accurately the position of both homogenates in the period of nitrite reduction. In both samples the occurrence of the first slight spoilage odours coincided with the beginning of nitrite reduction over the incubation period.

Since the analytical technique is extremely simple and well adapted to routine measurements, plans are being made to investigate the suitability of the method for the detection of possible spoilage in commercial fillets containing sufficient sodium nitrite (above about 30 p.p.m., Dyer and Castell, 1949) to inhibit the production of trimethylamine.

It will be noticed in the various Figures presented that the untreated cod homogenates spoiled after 5- to 7-day storage, and that the 200 p.p.m. sodium

nitrite added a minimum of 3 days to the keeping time. This confirms the work of Dyer and Castell (1949) in illustrating the value of nitrite in delaying spoilage odours.

GENERAL DISCUSSION

The methods presented for determining degree of spoilage by measuring chemical changes in the fish sample after an incubation period are most probably an indirect assessment of the bacterial population on the sample. The methods have certain advantages over the bacteria count measurement of spoilage, in that the results may be obtained in a much shorter time and the effects of only those bacteria which produce definite chemical changes are measured.

It must be pointed out that methods based on the measurement of the bacterial population, while expected to yield meaningful results in assessing the quality of fillets on the consumer market, could yield misleading results if applied to fillets freshly removed from the round fish. As pointed out by Castell *et al.* (1948), fillet quality in the latter situation depends more upon the condition of the round fish than upon the bacterial load the fillet picked up during the filleting operation. However, as the fillet ages, its bacterial load becomes the major factor governing its deterioration. Dyer and Dyer (1950) demonstrated this by showing that there was little difference in the keeping time of fillets taken from round fish stored 1 to 10 days in ice and having trimethylamine values ranging between 0.8 to 3.8.

SUMMARY

A method for the determination of spoilage in nitrite-treated cod fillets was sought by the determination of amino acids, ammonia, tyrosine value, volatile acids, and the rate of disappearance of nitrite in cod homogenates stored at 3°C. The results are discussed and indicated that only the latter three methods would be useful for this purpose. Of the three likely methods, only the determination of tyrosine value was selected for further study.

It was found that the tyrosine values among cod fillets of similar history and nitrite content were too scattered to be of use as a spoilage index. Much smaller standard deviations occurred with gains in tyrosine values during 3-hour incubation at room temperature. These latter measurements appeared useful as spoilage indices for they were found to increase significantly at the storage age when the spoilage odours first became evident. Precautions in the use of the method are discussed.

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Storage of Frozen Rosefish Fillets[1,2]

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ABSTRACT

Taste panel assessments of taste, texture, and grade of cooked samples, examination prior to cooking, and analyses of soluble actomyosin and of fat spoilage on frozen rosefish (*Sebastes marinus*) fillets, with and without treatment with ascorbic acid, stored at −10°F. (−23°C.) and +10°F. (−12°C.), are reported.

Rosefish fillets stored at +10°F. remained in good condition for 17 to 22 weeks, but became unpalatable in 7 months; stored at −10°F. these conditions applied after 30 weeks and 80 weeks.

Ascorbic acid prevented fading of the red pigment and delayed discoloration, but had no effect on the taste panel assessment. Almost no loss in actomyosin extractability occurred at −10°F. up to 85 weeks.

INTRODUCTION

In the previous paper of this series, on the storage of frozen plaice fillets (Dyer and Morton, 1956), a relationship was suggested between protein denaturation and lipid deterioration. Ascorbic acid was found ineffective in preventing lipid deterioration. This has now been investigated further with rosefish[4] (*Sebastes marinus*) fillets. Rosefish have a higher fat content (about 3%) as compared with the 1.5% for the plaice used previously (Dyer and Morton, 1956), and about 1% or less for cod and haddock (Lovern, 1953).

In addition, data on the frozen storage behaviour of rosefish fillets were needed. Bauernfeind *et al.* (1948) found that rosefish fillets became rancid in 6 months when stored at 12°F. (−11°C.), and in 10 months at 0°F. (−18°C.). When the fillets were dipped in a solution of 0.5 or 1% ascorbic acid before freezing, they were slightly rancid to good after 6 months at 12°F., and good after 10 months at 0°F. These were judged after being cooked in hot water. Ascorbic acid thus was found to improve the keeping quality of frozen rosefish fillets. On the other hand, brining was found to accelerate the development of rancidity, and the presence of ascorbic acid did not completely counteract this effect. The use of ascorbic acid preserved the red colour, which otherwise faded rather rapidly.

Because of its effect on development of rancidity (Banks, 1937), brining was not used in the present work.

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[1]Received for publication January 24, 1956.
[2]Paper No. 8 of a series "Proteins in Fish Muscle".
[3]Former member of staff.
[4]Other vernacular names used in various localities are: redfish, ocean perch, bream.

Miyauchi and Stansby (1952) stored ocean perch (rosefish) fillets at 0°F. At 13 weeks they found some discoloration and flavour loss, at 25 weeks some rancidity. After 29 weeks, discoloration and darkening occurred, and rancid flavour and odour were sufficiently pronounced to render the samples inedible.

EXPERIMENTAL

Rosefish fillets were prepared commercially in a local fish plant. One-half of the lot, the control, was dipped in water, drained, wrapped individually in cellophane in 5-lb. waxed cartons and frozen in Birdseye freezers. The other half was dipped for about one minute in a solution containing 0.3% ascorbic acid and 0.5% Krimko gel, a preparation of carrageenin, (Stoloff *et al.*, 1948), drained and processed as above. The frozen fillets were placed in constant temperature storage boxes, half of each lot at +10°F. (−12°C.) and the other half at −10°F. (−23°C.).

At intervals, samples were removed for taste panels and chemical analysis. These assessments, both organoleptic and chemical, were carried out as previously described (Dyer and Morton, 1956), with the following modifications: for determination of peroxide values, it was necessary to use a potentiometric rather than a visual titration for the red-coloured fat extract from the rosefish. A platinum electrode was substituted for the glass electrode in a Beckman pH meter, and the solution was stirred with a magnetic stirrer. The endpoint was obtained by plotting volume of N/100 thiosulphate against change in e.m.f. per unit volume of thiosulphate added. This modification gave very satisfactory results. The use of rosolic acid as an indicator gave better endpoints than phenolphthalein in the free fatty acid titration. Visual examinations of the extent of fading of the red pigment in the skin of the rosefish were also made.

RESULTS

The moisture content was 79.8 (±0.63)%. Total nitrogen content was 2.80 (±0.086)%, and non-protein nitrogen 0.30 (±0.041)%; hence the protein nitrogen content was approximately 2.50%. The crude fat content was 3.48 (±0.88)%, and varied more from sample to sample. The "albumin" or water-soluble protein nitrogen content was 0.56 (±0.085)%, i.e. 22% of the total protein. There was no change in any of these values throughout the storage period.

APPEARANCE AND ODOUR

The results of the organoleptic examination of the frozen fillets prior to cooking are quite significant (Table I). An orderly development of spoilage characteristics is evident. The first indication of a storage change is a slight darkening of the flesh. This is followed by a fading of the red skin colour, then a noticeable yellowing of the flesh under the skin. This yellowing then deepens, and is accompanied by a complete fading of the red skin pigment and development of dark spots in the flesh. These changes then progress still further, along with development of stale, musty and sour odours, characteristic of rancidity,

TABLE I.—Appearance and odour of stored frozen rosefish fillets prior to cooking. (F = flesh; S = skin.)

Storage (weeks)	Stored at +10°F.		Stored at −10°F.	
	Control	Treated	Control	Treated
0	S fresh-red	fresh-red	fresh-red	fresh-red
9	S fresh-red F slightly darker	fresh-red	fresh-red	fresh-red
18	S much bleached	fresh-red	fresh-red	fresh-red
24	S colourless F yellow	red yellow	fresh-red	fresh-red
28	S totally bleached	F slight discolor.	fresh-red	fresh-red
34	S pale, discoloured F yellow.	slight fading yellowish, few dark spots	fresh-red slightly darker	fresh-red
38	S faded F yellow*	faded yellow	some fading white	fresh-red
45	F yellow, sour-stale odour	yellow, sour-stale odour*	white	fresh-red
48	F very yellow, dark spots	yellow	S some red left F yellowish flesh and skin; slight off-odour	fresh-red
51	F very poor, yellow, stale	fair	almost good	fresh-red
54	...	S very poor F yellow, sour	faded yellowish*	fresh-red
59	...	...	F dark in spots musty, stale odour	some darkening
64	...	...	F dark spots yellowish	some discolouration stale odour
70	...	...	F brown under skin	still white
80	...	...	S bleached F dark, stale odour	red* dark, stale odour

*Judged unacceptable organoleptically.

and darkening of the flesh. Both storage temperature and ascorbic acid treatment markedly affect the development of the spoilage characteristics. From these results, it was judged that the samples stored at +10°F. had become unacceptable at about 34 and 45 weeks for the control and ascorbic acid-treated samples respectively, and at about 54 and 80 weeks for the corresponding samples held at −10°F. Thus ascorbic acid treatment delayed deterioration in the frozen rosefish fillets stored at +10°F. by some 11 weeks (from a storage period of about 8 months to about 10 months). At −10°F., the delay was some 26 weeks (from about 12 months to about 18 months). However, storage at −10°F., as compared with +10°F., was much more effective than the ascorbic acid treatment in prolonging the storage life of the fillets under these conditions. Both treatment with ascorbic acid and storage at a lower temperature seemed to act in the same way in delaying fat oxidation and the bleaching of the red skin pigment.

TASTE PANEL RATINGS

Texture. The average scores of the three panels in each sample are plotted in Fig. 1.

At −10°F. the ascorbic acid treatment had little effect. The scores decreased slightly up to 25 weeks, with possibly a slight dip at 28 weeks, and then decreased
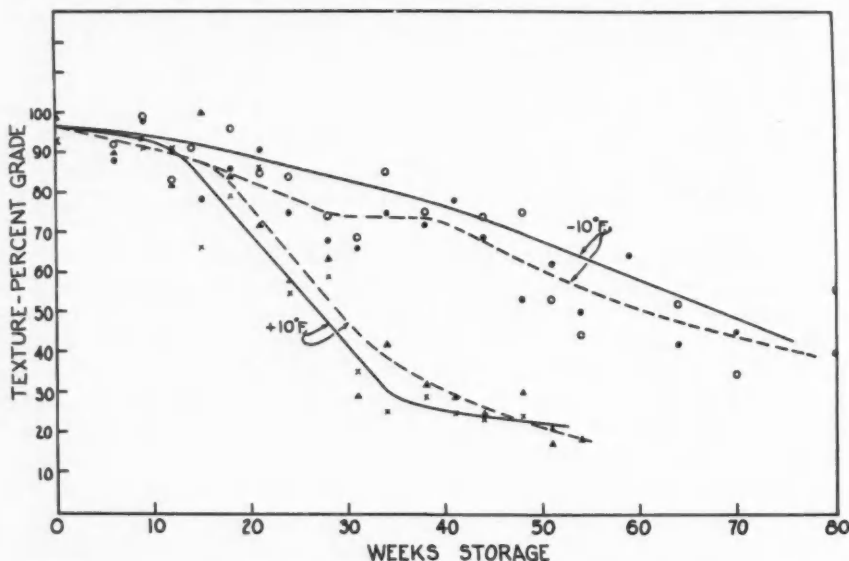

FIG. 1.—Texture gradings in frozen rosefish fillets stored at +10°F. (−12°C.) and −10°F. (−23°C.). ———— Control. - - - Ascorbic acid-treated.

gradually from 30 to 80 weeks, when the grade was down to about 50% from an initial level of 95%.

At +10°F., a slight decline took place to about 12 to 15 weeks, then a sharp decrease to 30 weeks, when the texture rating dropped to 30%. This was followed by a slow decrease to the end of the storage period at 54 weeks. Again ascorbic acid treatment had little effect. It is obvious that the storage temperature is very important, the texture reaching borderline before 6 months at +10°F., but remaining acceptable for up to a year at −10°F.

Taste. These results are shown in Fig. 2. At −10°F. there was a slow gradual decrease in grade from an initial value of 85 to 90% down to 80% at 15 weeks. This was followed by a decline to about 34 weeks (8 months), when the rating decreased to 65%. This in turn was followed by a more gradual decrease to 80 weeks where the grade was about 45%; again ascorbic acid treatment had little effect.

At +10°F. the grade decreased only very slowly for a period of 15 weeks. This was followed by a sharp decline between 15 and 34 weeks, by which time

the grade of the control sample fell to about 35%. The rating then decreased more slowly to a level of about 20% at one year's storage. The ratings for the ascorbic acid-treated rosefish also declined sharply from 15 to 34 weeks, but did not go quite so low, reaching about 45% at 34 weeks, then decreasing to 30% at one year. The results are quite similar to the texture ratings.
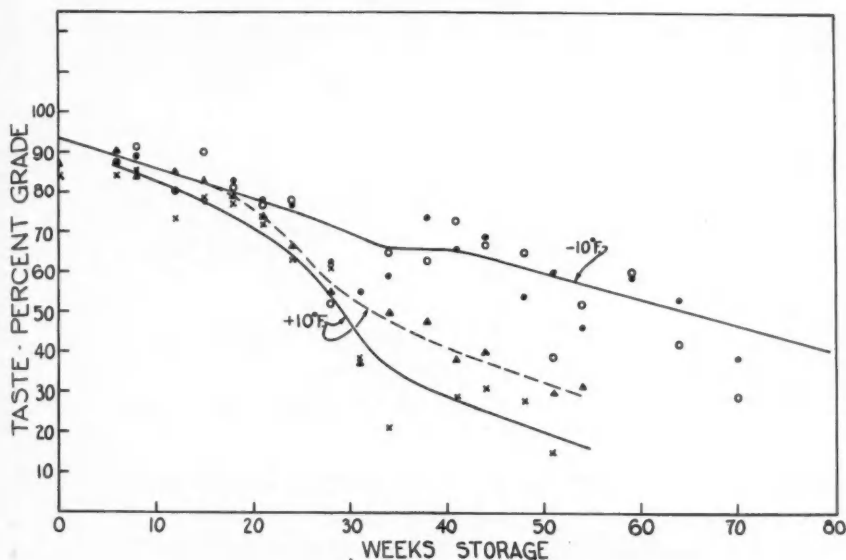
FIG. 2.—Taste gradings in frozen rosefish fillets stored at +10°F. (−12°C.) and −10°F. (−23°C.). ——— Control. - - - Ascorbic acid-treated.

Overall grade. These results, Fig. 3, are the final ratings given to the samples by the taste panel, and are mostly determined by the taste and texture ratings, somewhat modified by appearance and odour.

At −10°F. the ratings remained above 90% up to 15 weeks. Between 15 and 30 weeks there was a decline from 90 to 70%, followed by a period of almost no change between 35 and 45 weeks. From this point up to 80 weeks, the ratings declined more rapidly to values of about 45%. In this range, the control samples fell considerably faster. These results are very similar to those for the texture and taste.

At +10°F. the ratings declined from 90 to 70% in about 20 weeks, compared to 30 weeks for the samples stored at −10°F. There was then a sharp drop until about 35 weeks, by which time the grade fell to about 30%, followed by a slow decrease to the end of the storage period. The ascorbic acid-treated samples graded a few points higher in this last phase, but were otherwise indistinguishable.

In contrast to the results from organoleptic examination of the samples before cooking, the taste panel results showed almost no effect due to ascorbic

acid treatment. On the other hand, storage temperature is very important; the samples stored at −10°F. were just reaching the borderline at 80 weeks, i.e. 18 months, while those stored at +10°F. had become unacceptable at about 30 weeks, i.e. about 7 months.
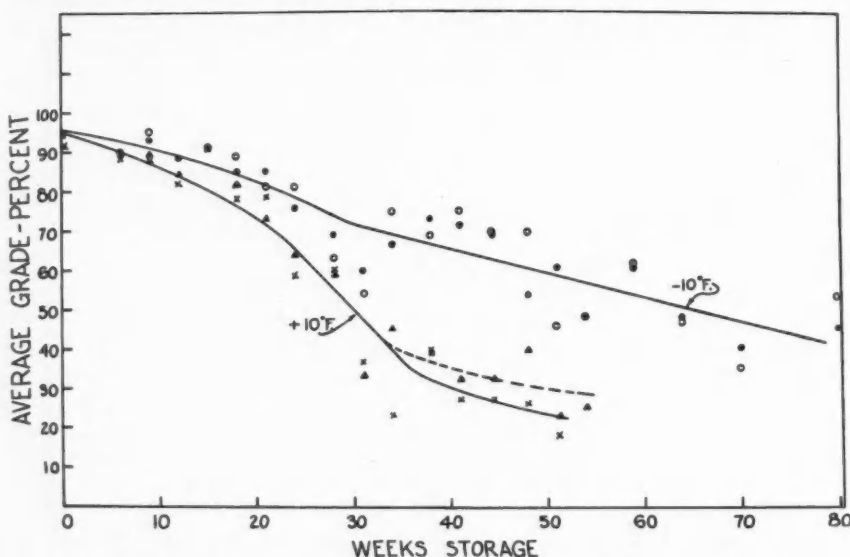

FIG. 3.—Average taste panel grade in frozen rosefish fillets stored at +10°F. (−12°C.) and −10°F. (−23°C.). ———— Control. - - - Ascorbic acid-treated.

CHEMICAL ANALYSES

Extractable protein. These results are shown in Fig. 4. Total soluble protein values yielded curves essentially parallel to those for extractable actomyosin and are not shown. The actomyosin fraction, that is, the protein which can be centrifuged out when the salt extract is diluted 1 to 10 with water at 0°C. and centrifuged after standing 4 to 6 hours or overnight, is plotted as percentage, expressed as nitrogen, of the fish tissue.

At −10°F., the results are remarkable. The extractable actomyosin in the control fell slightly from 1.7% initially to 1.5% at about 12 weeks, and then showed no change up to 85 weeks. Similarly, that of the ascorbic acid-treated fillets fell from 1.6 to 1.5% and remained at this value.

At +10°F., the control remained the same as at −10°F. up to 21 weeks, fell sharply from 1.5% almost to 1.0% between 21 and 30 weeks, and then remained steady up to the termination of the experiment at 85 weeks. The ascorbic acid-treated sample behaved in the same way up to a year's storage, but subsequently decreased sharply between 58 and 85 weeks to a level of about 0.5%.

These results are reminiscent of those for halibut (Dyer, 1951), where there
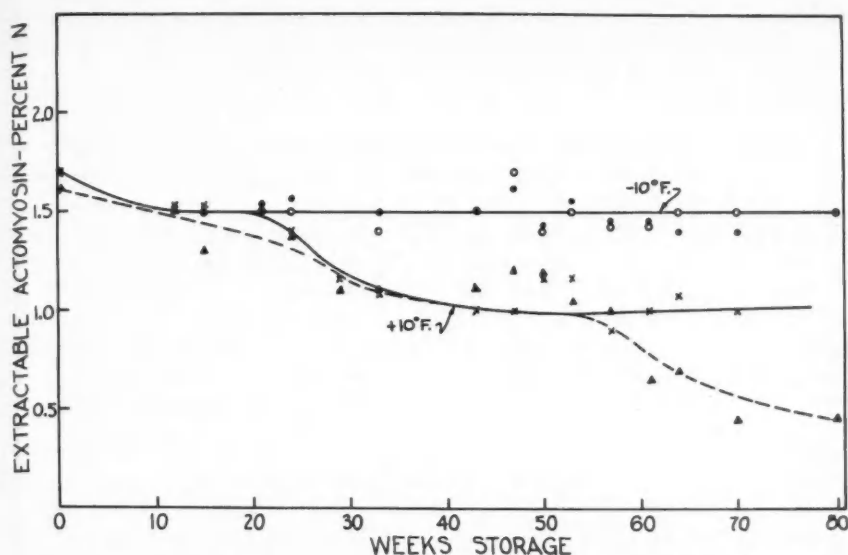
Fig. 4.—Extractable actomyosin, as percentage N of fish, in frozen rosefish fillets stored at
+10°F. (−12°C.) and −10°F. (−23°C.). ——— Control. − − − Ascorbic acid-treated.

was only a slight decrease in soluble actomyosin, and are in sharp contrast to the
other fish species so far investigated.

Free fatty acids. The free fatty acid values are shown in Table II. Up to
42 weeks there was very little change, and no difference between control and

TABLE II.—Free fatty acid of extracted fat in frozen stored rosefish fillets.

Time in storage	Free fatty acid (calculated as oleic acid)			
	Control		Treated	
	+10°F.	−10°F.	+10°F.	−10°F.
Weeks	%	%	%	%
1	. . .	6.2	. . .	4.4
9	10.4	. . .	6.5	. . .
13	7.2	. . .	4.9	. . .
21	13.2	2.7	6.5	3.4
26	5.1	1.7	5.1	2.0
33	7.0	6.3	8.7	2.2
42	2.6	5.9	4.6	6.3

ascorbic acid treatments. The samples stored at −10°F. had lower average values
than the samples at +10°F.

Peroxide values. These are shown in Fig. 5, expressed as milliequivalents per
100 g. extracted fat.

The rosefish fillets stored at +10°F. showed a large increase in peroxide
value, rising between 10 to 34 weeks from 0.2 to a level of 3.5. This was

followed by a sharp decrease with rather erratic values varying from 1 to 3 up to about 70 weeks' storage, and showing values of about 4 at 80 weeks. Thus, a rapid formation of peroxide occurred between 10 and 30 weeks. The ascorbic acid-treated samples at +10°F. evidenced some delay in peroxide development,

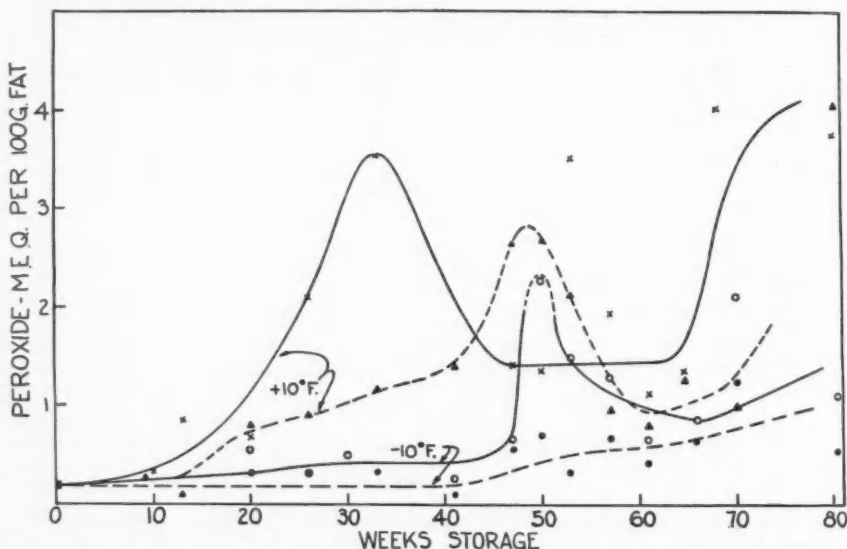Fig. 5.—Peroxide values, as milliequivalents per 100 g. extracted fat, in frozen rosefish fillets stored at +10°F. (−12°C.) and −10°F. (−23°C.). ———— Control. - - - Ascorbic acid-treated.

which began to increase at about 15 weeks, showing a rapid increase at about 40 weeks to a maximum of 2.8 at 48 weeks, then declining rapidly. Thus, ascorbic acid did delay peroxide formation. These results more closely parallel the organoleptic observations prior to cooking than those obtained on the cooked product.

At −10°F. there was a very slight increase in peroxide value up to 45 weeks. A sharp rise in the control sample to a maximum value of 2.3 at 50 weeks then occurred, followed by a decline. The ascorbic acid-treated samples remained unchanged up to 45 weeks, after which the values increased slowly up to approximately 0.8 at 80 weeks. Here again ascorbic acid treatment somewhat delayed peroxide formation. However, lowering the temperature of storage from +10 to −10°F. was much more effective than treatment with ascorbic acid in delaying peroxide formation.

DISCUSSION

Storage Qualities of Frozen Rosefish Fillets

The taste panel results on frozen rosefish fillets show that they kept in very good condition for 4 to 5 months when rapidly frozen, wrapped in cellophane, and packed in waxed cartons and stored at +10°F. At −10°F. they kept well

for 6 to 8 months. However, the fillets did not become unacceptable until stored for periods of 7 months and 18 months respectively. This agrees with the previously cited results of Bauernfeind *et al.* (1948) and Miyauchi and Stansby (1952).

The results of organoleptic examination before cooking were considerably different. After storage at +10°F. the raw thawed fillets were judged unacceptable at 8 months, as compared with 7 months for the taste panel results on the cooked fish; after storage at −10°F. the corresponding periods were 12 and 18 months. Thus, the two examinations do not give the same results.

Even though it is a relatively fatty fish, rosefish stores well. At +10°F. the keeping time for cod, plaice, and halibut (Dyer, 1951; Dyer and Morton, 1956) are approximately 2 to 3 months, 6 months, and 8 months respectively, as compared with about 7 months now obtained for rosefish. At −10°F. the values are 10 months for cod, and 18 months for redfish and halibut.

Ascorbic Acid Treatment

Comparison of the taste panel results of the untreated and ascorbic acid-treated samples shows little effect of the treatment up to the unacceptable stages. On the other hand, the examination of the samples prior to cooking showed that ascorbic acid delayed the fading of the red skin pigment, and also the yellowing of the fatty tissue in the flesh and the flesh discoloration. From the consumer's standpoint, ascorbic acid has definitely improved the appearance of the stored product, even though it may have had little effect on the taste of the cooked fillets.

These results corroborate our previous experience with ascorbic acid in plaice fillets (Dyer and Morton, 1956) and the results of Banks (1952) which indicated that ascorbic acid treatment may delay somewhat the peroxide formation and is effective in preventing fading of the skin pigment, but seems to have very little effect on the results of the taste panel testing. The results, however, are interesting enough to suggest it may be worth while to try other antioxidants such as butylated hydroxy anisole either alone or in conjunction with ascorbic acid.

Protein Solubility

As with the other species of fish formerly investigated (Dyer, 1951; Dyer and Morton, 1956), there was no detectable change in the albumin fraction. However, there was almost no change in the extractable actomyosin fraction up to 85 weeks' storage at −10°F. As discussed previously, this again confirms the sharp contrast between cod and the more fatty fish as plaice, halibut, and rosefish. After long-term storage, the extractable actomyosin in cod falls to almost zero, in plaice to about one-quarter of the original amount, in halibut to about one-quarter after 65 weeks at +10°F. but only one-half after 85 weeks at −10°F., and now we find almost no decrease in rosefish after 85 weeks at −10°F.

At +10°F. the actomyosin drops about two-thirds between 20 and 30 weeks and remains at this figure. Thus, some change occurs at this temperature but not at −10°F.

The reasons for the greater stability of actomyosin in fatty fish are not as yet clear. The evidence obtained indicates that the more fatty the fish, the greater is the resistance of the actomyosin to denaturation during frozen storage. Both the amount and type of lipoproteins and nucleoproteins could differ appreciably between the non-fatty and fatty species of fish. As yet there are insufficient data on the amounts and identity of these compounds in the muscle of the various fish species.

The apparent relationship between fat oxidation and the actomyosin denaturation is significant. If they are related as cause and effect, we cannot say as yet which is which. Lipid oxidation could cause a dissociation of the lipoprotein, and the freed protein might then be more readily denatured. On the other hand, a denaturation of the protein moiety might result in the splitting off of the lipid portion, which might then be more easily oxidized.

However, we have shown that while ascorbic acid does delay peroxide formation somewhat, it has little effect on the protein extractability. This evidence favours the latter alternative above.

The data available so far on free fatty acid formation now appear more significant. As suggested previously (Dyer and Morton, 1956) the formation of even a small amount of free fatty acid, or of soaps of these, could greatly modify the peptizability of the large actomyosin protein complex and have a major effect on its hydration. The rosefish shows (Table II) only some 2 to 6% free fatty acid formation at −10F°., and in most cases only little more at +10°F. storage. In plaice, the correlation between free fatty acid formation and actomyosin insolubility is good, the former rising to levels of about 35 or 40% (as oleic acid) as the protein extractability reached its lowest level. Previous work with cod (Dyer, 1951) showed that both denaturation and free fatty acid development were very rapid. In halibut Dyer (1951) found little loss in actomyosin extractability at 0°F. and at −10°F. for up to 70 weeks' storage, but there was considerable at +10°F. No formation of free fatty acid occurred at −10°F. (McMillan and Dyer, unpublished). At +10°F., however, the level rose rapidly to about 12% at 9 weeks, increasing to about 20% at 30 weeks, which is remarkably parallel to the protein denaturation. At 0°F. the free fatty acid level rose to 10% at 10 weeks and remained at this level. However, the protein denaturation was only slightly greater than at −10°F. Perhaps the level of free fatty acid formation is significant. Presumably the free fatty acid arises by the action of lipase, and the amount and also the activity of this enzyme could be quite different in the various species.

CONCLUSIONS

Storage temperature greatly affected the keeping quality of frozen rosefish fillets. These kept in good condition as assessed by taste panels up to 4 to 5 months at +10°F. and up to 6 to 8 months at −10°F.; they were not judged unacceptable until 7 months and 18 months respectively. Ascorbic acid treatment did not affect the taste panel results, but did prevent the fading of the red skin

pigments and delayed yellowing of the fatty tissue in the flesh and the flesh discoloration when the fillets were examined prior to cooking. It also delayed peroxide formation.

No decrease in protein extractability occurred in the samples at $-10°F$. There was about a one-third decrease between 20 and 30 weeks at $+10°F$. These results correlate reasonably well with the taste panel results.

The results of peroxide value and free fatty acid determination on various species of fish show that the latter appear to correlate better with the protein denaturation.

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Surface and Bottom Currents in the Strait of Georgia[1]

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ABSTRACT

Measurements of the currents close to the bottom and at the surface have been made at six stations along a section across the Strait of Georgia from Point Roberts to Galiano Island, and at two stations in Trincomali Channel. After adjusting to the maximum tidal range the mean bottom currents were about 0.3 knot with a maximum of 1 knot. At the surface the mean flood current was 0.45 knot and the mean ebb 0.85 knot, with maxima up to 2 knots. The bottom currents were periodic and appeared to be essentially tidal in character, while the surface currents were a combination of tidal and river run-off flows.

INTRODUCTION

In order to gain some information on the magnitudes of the currents close to the bottom in the Strait of Georgia, British Columbia, measurements were made at six stations distributed along a line from the vicinity of Point Roberts in the east to Galiano Island in the west (Fig. 1). In addition, two stations were occupied in Trincomali Channel between Galiano Island and Saltspring Island. Measurements were also made of the currents at the surface at all but one of the stations.

Each station was occupied for a full tidal cycle (about 25 hours), and the number of stations was determined by the ship time available for the study. The locations selected in the Strait of Georgia were arranged to span the strait and to obtain observations at representative depths. There were no previous observations available to guide the choice of location. In Table I are listed the station positions and other pertinent data.

METHODS

The observations were all made from the C.G.S. *Marabell,* of the Canadian Hydrographic Service, lying to a single anchor at the positions indicated.

The bottom currents were measured with an Ekman current meter (Ekman, 1932) suspended within a brass frame (Fig. 2). When placed upon a level floor the centre of the propeller was 16 inches (41 cm.) above the floor. It is assumed that the bottom currents refer to this height above the sea bottom because there was no evidence that the frame sank appreciably into the firm mud, or mud and sand, which constituted the bottom at each station. In this application the Ekman current meter was not operated by messengers. Instead, the supporting wire upon which the meter was lowered to the bottom was attached to the frame and meter

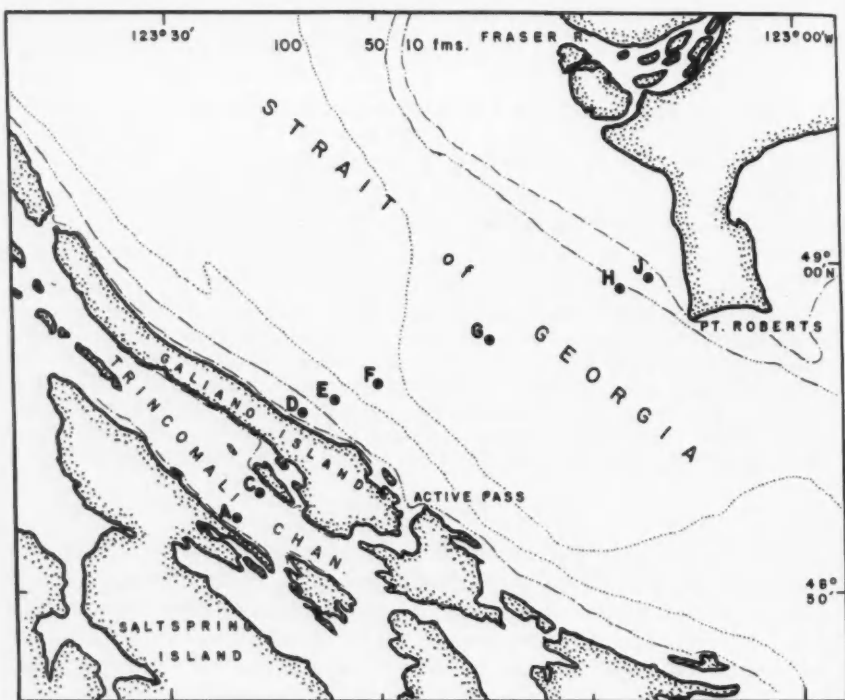[1]Received for publication March 1, 1956.

Fig. 1.—Location of current stations in Trincomali Channel and the Strait of Georgia.

in such a manner that the meter recorded only when the frame was resting on the bottom with the wire slacked off. The frame served the dual purpose of holding the meter clear of the bottom and keeping the slack wire from fouling the meter.

The bottom current measurements were made at half-hourly intervals at all stations by lowering the frame to the bottom and allowing it to remain there for 2 to 5 minutes. Since the frame rested upon the bottom with the wire slack the meter was not affected by any movement of the ship. The meter recorded both speed and direction.

The surface currents were measured with a current pole and calibrated log line (Southern, 1938). The direction of the current was determined relative to known landmarks since no pelorus was available at the stern of the vessel. The pole floated vertically with 12 feet (3.7 meters) of its length immersed, and therefore indicated an average speed for the surface layer of water to this depth. The surface currents were measured at hourly intervals at all stations except at Station A where they were not observed.
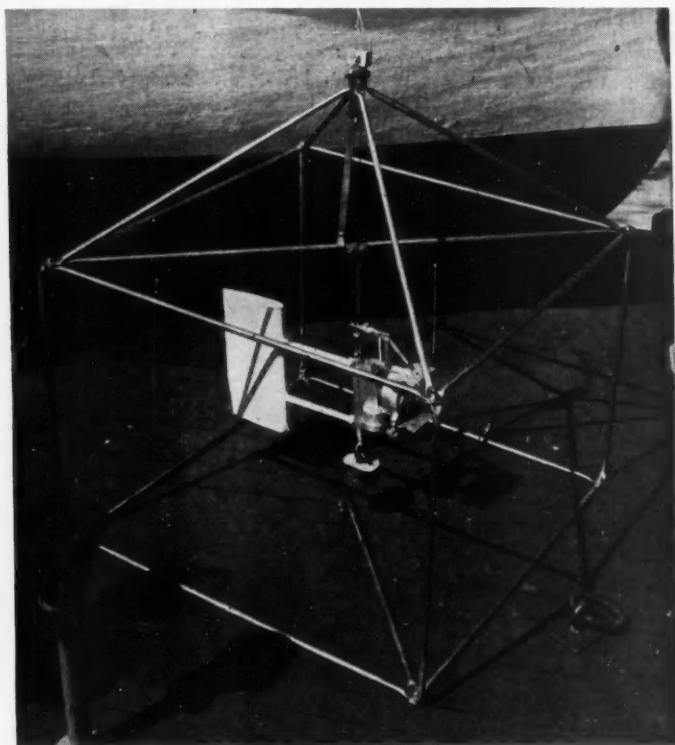
FIG. 2.—Ekman current meter mounted in frame for bottom current measurements.

TABLE I.—Station data relating to measurements of currents in Trincomali Channel and the Strait of Georgia, June–July, 1954.

Station	Latitude N.	Longitude W.	Depth		Date of occupation, 1954	Range of tide
			fm.	m.		ft.
A	48° 52.1′	123° 26.4′	15	27	31 May–1 June	11.4
C	48° 52.9′	123° 25.5′	20	37	1– 2 June	11.5
D	48° 55.4′	123° 23.5′	23	42	9–10 June	7.6
E	48° 55.7′	123° 21.8′	84	154	3– 4 June	12.5
F	48° 56.3′	123° 19.9′	105	192	2– 3 June	13.3
G	48° 57.6′	123° 14.5′	78	143	24–25 June	9.3
H	48° 59.3′	123° 08.4′	54	99	2– 3 July	12.2
J	48° 59.6′	123° 07.0′	23	42	8– 9 July	7.5

RESULTS

A total of 393 measurements of the bottom current was made, the measurements being distributed almost uniformly among the eight stations. Also, 197 measurements of surface current were made at stations C to J. The individual observations of speed are presented in Fig. 3A to 3D, with smoothed curves drawn between the points. The Figures represent the actual measured speeds, the points being plotted above or below the zero speed axis for flood and ebb conditions respectively. The mean directions observed for flood and ebb are indicated on the Figures together with the deviation of values about this mean. Curves of tide height are shown on the same Figures for comparison.

The values of the maximum and mean speeds are summarized in Table II.

TABLE II.—Observed bottom and surface current speeds in Trincomali Channel and the Strait of Georgia.

Station	Tidal range ratio	Bottom currents				Surface currents			
		Maximum		Mean		Maximum		Mean	
		Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb
		knot	*knot*	*knot*	*knot*	*knots*	*knots*	*knot*	*knot*
A	.96	0.75	0.6	0.4	0.3	—	—	—	—
C	1.00	0.8	0.6	0.35	0.2	1.0	1.4	0.45	0.6
D	.55	0.3	0.35	0.1	0.15	0	1.1	0	0.3
E	.91	0.7	0.6	0.25	0.15	1.2	1.1	0.7	0.65
F	.97	0.8	0.4	0.35	0.15	1.6	1.1	0.75	0.55
G	.68	0.4	0.6	0.15	0.2	0	1.5	0	0.95
H	.89	0.95	0.7	0.5	0.3	1.2	1.4	0.55	0.8
J	.55	0.3	0.35	0.15	0.15	0.8	1.0	0.3	0.5

The 'tidal range ratio' is the ratio of the range of the tide during the period of observation to the maximum range predicted for the station during 1954. The 'range' of the tide is the difference in height between lower low water and higher high water on any particular day.

DISCUSSION OF RESULTS

CORRECTION FOR TIDAL RANGE

Observations were made at some of the stations (A,C,E,F,H) when the tidal range was close to the maximum value predicted for any time during the year and it may be assumed that the measurements at these stations indicate the maximum or near-maximum tidal currents to be expected. At stations D, G and J the tidal ranges were appreciably less than the maximum and the currents may therefore be expected to be less than the maximum. To bring all the stations to the same basis for comparison, the measured currents were adjusted to values corresponding to the maximum tidal range by dividing by the tidal range ratio referred to above. This adjustment assumes that the tidal range and current are linearly related as is commonly the case for tidal passages.

The distribution of current speeds thus obtained is summarized in Table III. In Trincomali Channel 70% of the adjusted currents lie between 0 and 0.5 knot, and only 2% are above 0.75 knot. In the Strait of Georgia 86% lie between 0 and 0.5 knot, and only 2% are above 0.75 knot.

There is no obvious correlation between depth and bottom current. The strongest currents, when adjusted to the maximum tidal range (Table III), were observed at an intermediate depth at station *H* whereas the second strongest were at the deepest station (*F*).

TABLE III.—Bottom and surface current speeds in Trincomali Channel and the Strait of Georgia after adjustment to the maximum tidal range for the year.

	Bottom currents				Surface currents			
	Maximum		Mean		Maximum		Mean	
Station	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb
	knots	*knot*	*knot*	*knot*	*knots*	*knots*	*knot*	*knots*
A	0.8	0.65	0.4	0.3	—	—	—	—
C	0.8	0.6	0.35	0.2	1.0	1.4	0.45	0.6
D	0.55	0.65	0.2	0.25	0	2.0	0	0.55
E	0.75	0.65	0.25	0.15	1.3	1.2	0.75	0.7
F	0.8	0.4	0.35	0.15	1.65	1.15	0.75	0.55
G	0.6	0.9	0.2	0.3	0	2.2	0	1.4
H	1.05	0.8	0.55	0.35	1.35	1.55	0.6	0.9
J	0.55	0.65	0.25	0.25	1.45	1.8	0.55	0.9
Mean (*D–J*)		0.3	0.25				0.45	0.85

DIRECTION OF CURRENTS

The mean current directions are given in Fig. 3A to D. In Trincomali Channel both the surface and the bottom currents were directed substantially along the channel, the flood being to the northwest and the ebb to the southeast. The individual directions lay within a relatively small range of 20 degrees either side of the mean. This is to be expected in a straight passage such as Trincomali Channel.

At the stations in the Strait of Georgia the overall mean direction of the flood was 310° true and of the ebb was 120° true. The mean values for each station lay within 20 degrees either side of this overall mean. The individual current directions, however, varied over a larger range. For the bottom currents the values ranged from 30 to 50 degrees either side of the mean while the surface currents ranged from 20 to 60 degrees either side of the mean. Even at Station *D* close to the steep shoreline of Galiano Island the currents, both surface and bottom, had significant components toward or away from the shore at times. It is presumed that this is evidence of meandering of the currents or of eddies superimposed upon the mean flow. The observational interval of ½ or 1 hour is too long for it to be possible to make any estimate of the frequency of meander.

When the surface currents are averaged across the strait it is found that the net ebb is significantly larger than the net flood (Table III). This is to be expected since the bulk of the run-off from the Fraser River remains in the surface layer while in the Strait of Georgia and making its way southeast toward Juan de Fuca Strait. A compensating preponderance of flood over ebb is to be expected in the deeper water. A slight difference between the mean flood and ebb at the bottom (0.3 knot against 0.25 knot) is evident but is probably
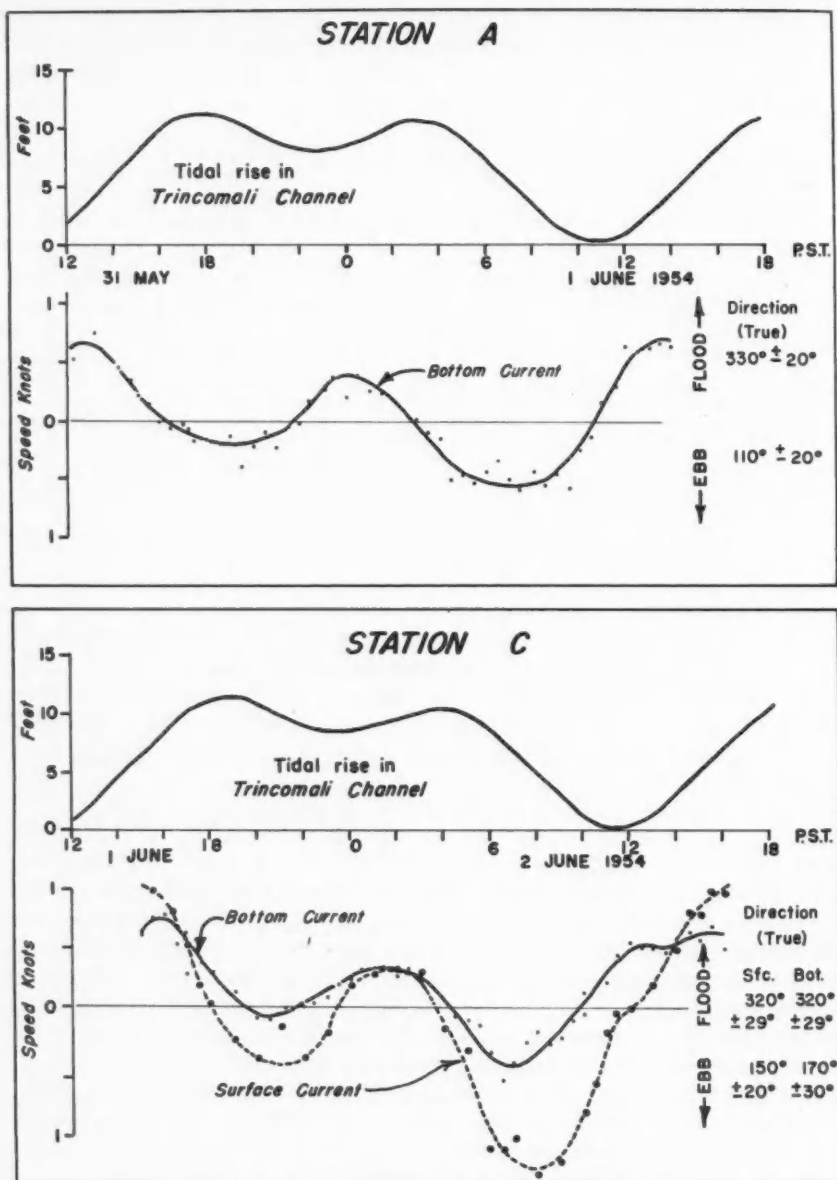
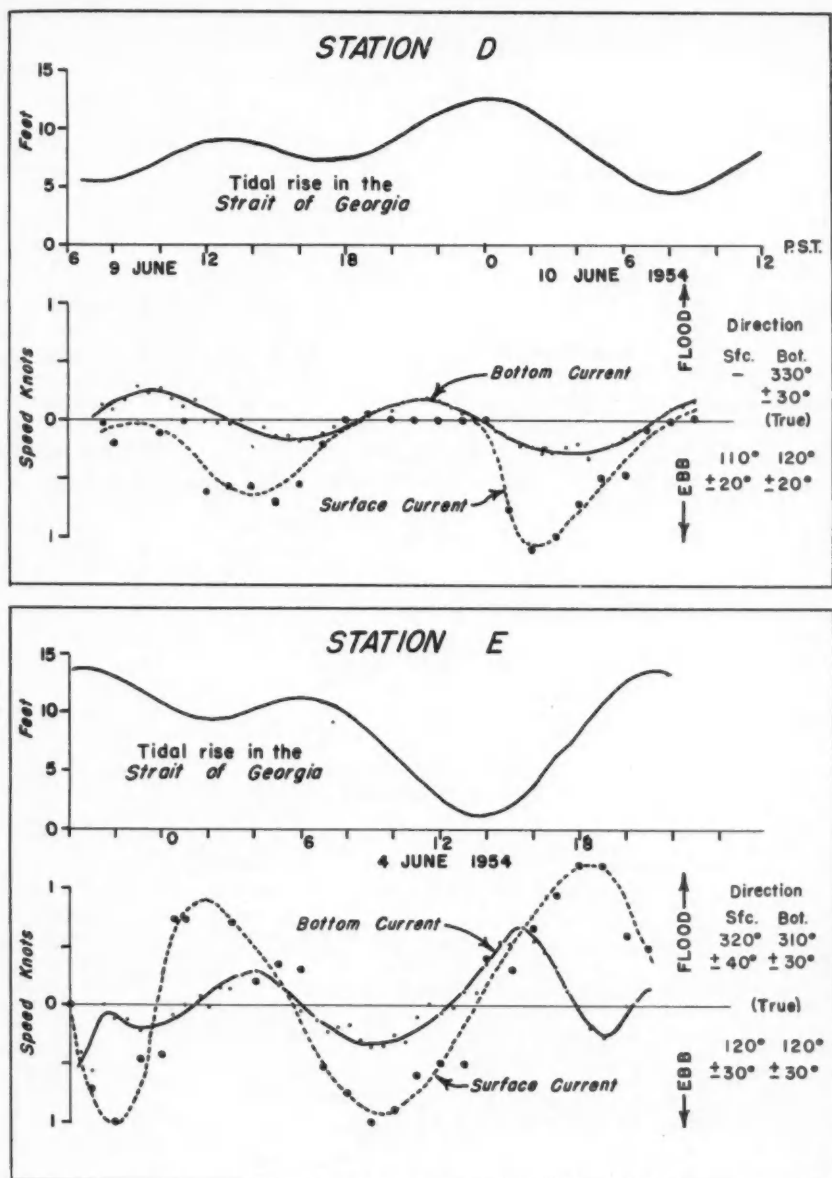Fig. 3A.—Surface and bottom currents at Stations A and C in Trincomali Channel.

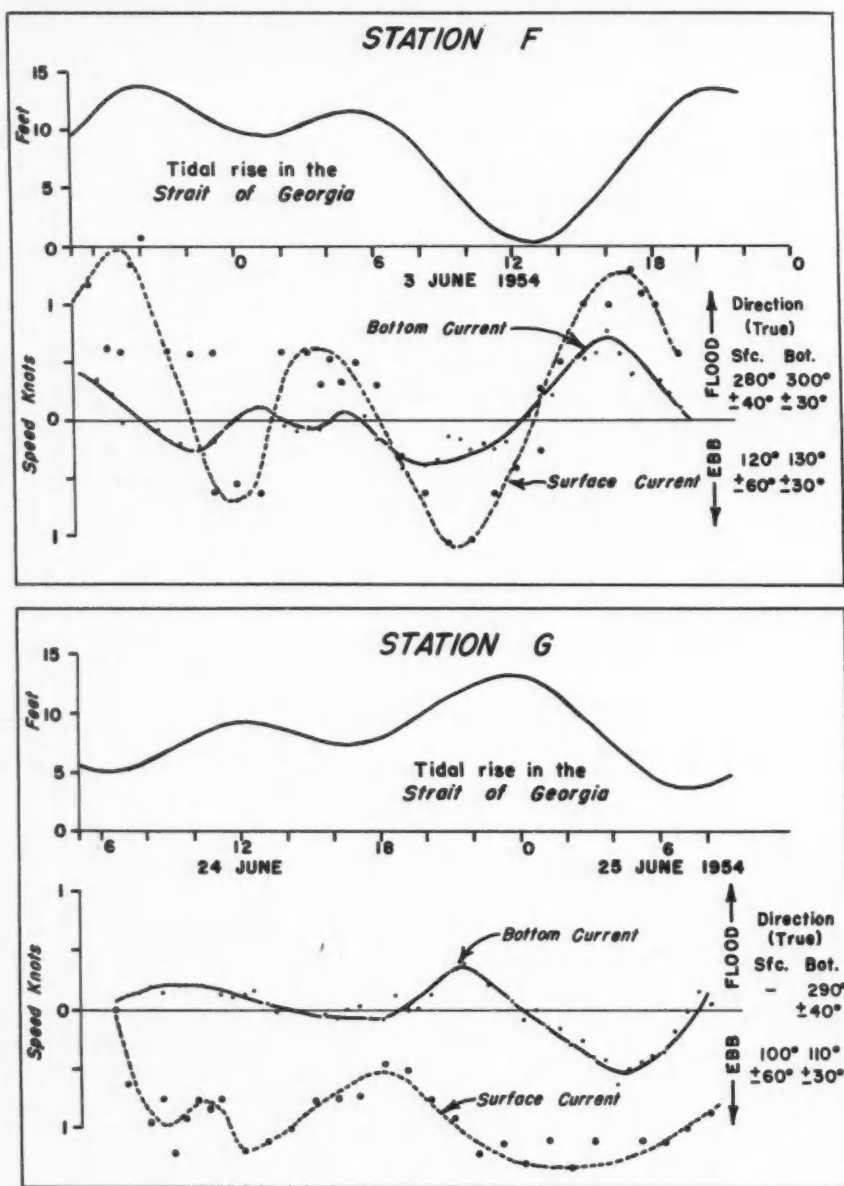FIG. 3B.—Surface and bottom currents at Stations *D* and *E* in the Strait of Georgia.

FIG. 3C.—Surface and bottom currents at Stations F and G in the Strait of Georgia.
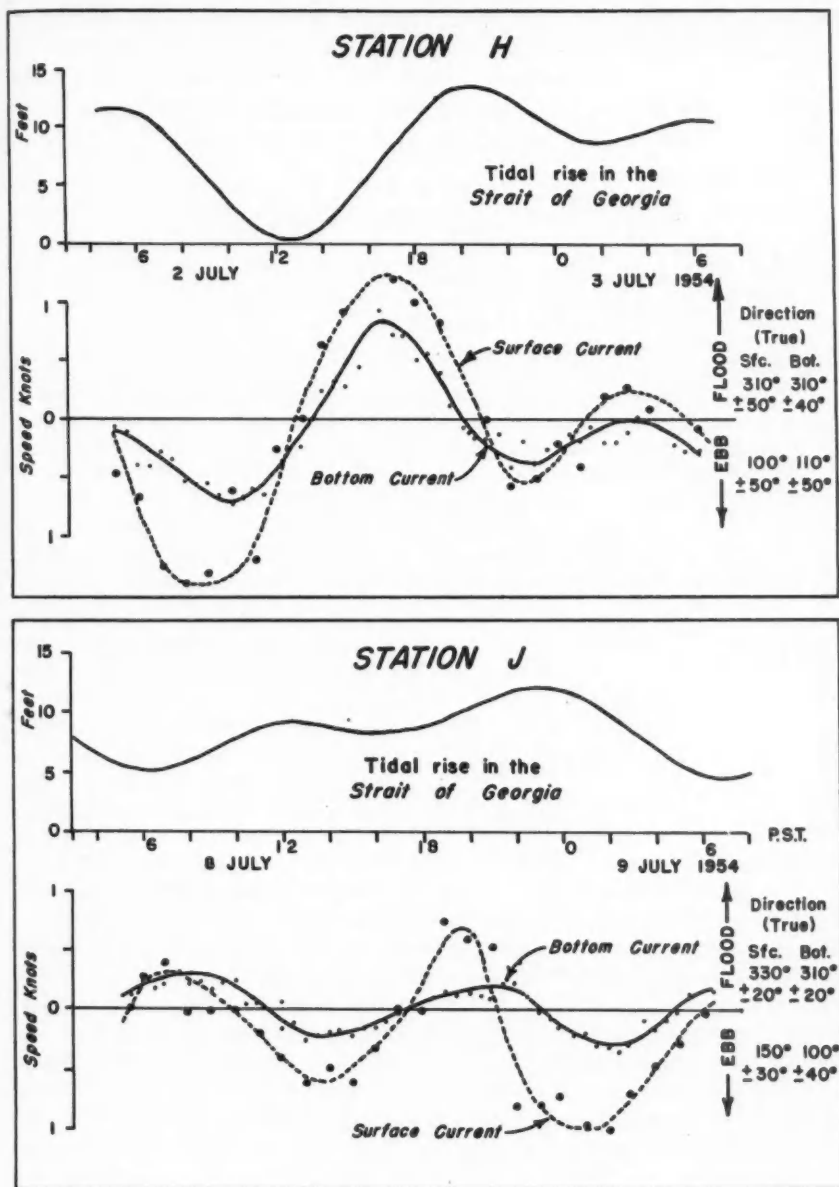
Fig. 3D.—Surface and bottom currents at Stations *H* and *J* in the Strait of Georgia.

not statistically significant. The compensating inflow is likely to be distributed over a greater range of depth than the outflow and may therefore be expected to be of smaller magnitude. Measurements at a number of depths between the surface and the bottom would be necessary to determine the character of the inflow.

PHASE OF CURRENTS

Generally the surface and bottom currents were in phase within an hour. The chief exceptions were during the flood at Station E (Fig. 3B), and at Station G (Fig. 3D) where there appeared to be little relation between the two levels. Slack water occurred on the average within 1 hour of high or low water.

EFFECT OF WIND

For the greater part of the period of observation the wind speed was less than 5 knots and it is considered that the wind effect can be ignored, even on the surface currents.

TURBIDITY CURRENTS

The bottom currents measured in the present series may be attributed to tidal currents on account of their regular periodicity. The extensive mud banks, and the amount of material brought down annually by the Fraser River and deposited on these banks, suggest that mud slides or turbidity currents may be expected to occur at times in this region of the Strait of Georgia. As far as is known no evidence of such movements has ever been recorded. Such currents would, by their very nature, consist of water which would be appreciably denser than the surface layer and would remain beneath it. Possibly the only method for detecting them would be to carry out regular precise depth surveys, as has been done elsewhere. It is unlikely, however, that such turbidity currents play a significant part in the general circulation of the waters of the Strait of Georgia.

ACKNOWLEDGEMENTS

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Some Temperature and Salinity Records from the Canadian Arctic during 1954 and 1955[1,2]

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ABSTRACT

A series of fourteen oceanographic stations were occupied from May 1954 to August 1955 in the Canadian Arctic. Temperatures and salinities were usually recorded at six levels down to 100 m. Low salinities, less than 30‰, were recorded at all depths at two stations in Coronation Gulf and near Cambridge Bay during the summer of 1954. Data from eight stations in the vicinity of the northern coast of Baffin Island during the winter 1954–55 and the following summer revealed some of the seasonal changes in temperature and salinity.

INTRODUCTION

WHILE collecting marine animals in the Canadian Arctic from May 1954 to August 1955 in the region between Coppermine and Pond Inlet (see accompanying Figure) I was able to make a series of observations on the temperature and salinity of the sea water. Very few data have been recorded previously in this region which lies between the Beaufort Sea and Baffin Bay, both the subjects of recent examination by Canadian and United States oceanographers (Anon., 1955; Dunbar, 1951). Some surface and sub-surface temperatures had been recorded by the early explorers of the archipelago (Prestwich, 1875) and surface temperatures and salinities were measured by Sgt. H. Larsen of the Royal Canadian Mounted Police in the Beaufort Sea and Coronation Gulf during 1935 and 1937 (Tully, 1952). Extensive oceanographic data were obtained from Baffin Bay, the eastern limit of the region described here, by the *Godthaab* Expedition 1928 (Riis-Carstensen, 1931).

The main purpose of my collections during 1954 and 1955 was to obtain quantitative samples of the marine benthos; the journey and collecting grounds have been described elsewhere (Ellis, in press). The temperature and salinity measurements that were made suffered in accuracy because at no time during the period of 15 months were there adequate laboratory facilities for the accurate recording and titrating required for such data. The temperatures, for instance, were read either in small open boats or on the sea ice[3] where the collections were made. During cold weather when the air temperatures were lower than 0°C. (from October until May) the readings were made within a tent pitched

[3]Collections from October 1954 to June 1955 were made through the sea ice at floe edges, through breathing holes of the "jar" seal (*Phoca hispida*) at tide cracks or through holes chopped in the ice.

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on the ice and heated by primus stoves. However, on many occasions the air temperature within the tent remained below the minimum temperature recorded by the auxiliary thermometer, i.e. −5°C., and the reversing thermometer could therefore not be equilibrated with the air temperature. The temperatures were consequently read two or three times before the mercury in the auxiliary thermometer had dropped below the minimum recordable level. Corrections were applied to each reading and a mean value was calculated. The difference between the extremes of the corrected temperatures was in only one case (collection B4, 90 m. depth, Table I) greater than the error introduced by the limits of accuracy

TABLE I.—Temperatures and salinities recorded during 1954 and 1955.

Collection No.	Date	Station No.	Locality	Depth	Temperature	Salinity Hydrometer	Salinity Titration
	1954			m.	°C.	‰	‰
B1	May 28	B2	Coronation Gulf	0	−1.55	27.4	27.5
			68° 08′N.	5	−1.40	27.4	27.7
			114° 25′W.	10	−1.50	27.8	27.5
			Through seal hole	25	...	...	28.0
				50	...	...	28.3
				100	...	...	28.4
				(NB)*			
B2	Aug. 10	B17	West of Cambridge	0	+4.45	...	13.5
			Bay	5	+3.85	...	23.8
			69° 05′N.	10	+0.80	...	27.7
			105° 45′W.	25	−0.85	...	28.8
			From boat	50	−1.45	...	29.4
				80	−1.50	...	29.7
				85(B)			
B3	Sept. 22	B23	Arctic Bay	0	+1.70	...	29.2
			73° 02′N.	5	+1.70	...	29.4
			85° 05′W.	10	+1.70	...	29.5
			From boat	25	+1.50	...	30.5
				50	−0.90	...	32.4
				90	−1.55	...	32.6
				95(B)			
B4	Oct. 28	B27	Arctic Bay	0	−1.60	...	30.9
			73° 02′N.	5	−1.60	...	30.6
			85° 05′W.	10	−1.55	...	...
			Through thin ice	25	−1.35	...	31.0
				50	−0.90	...	32.0
				90	−1.50(−1.70)	...	32.5
				95(B)			
B5	Nov. 18	B29	Adam Sound	0	−1.65	31.6	...
			73° 00′N.	5	−1.65	31.6	...
			85° 10′W.	10	−1.65	31.6	...
			Through thin ice	25	−1.65	31.6	...
				50	−1.00	31.8	...
				100	−1.35	32.6	...
				(NB)			
B6	Dec. 28	B29	Adam Sound	0	−1.70	32.4	...
			73° 00′N.	5	−1.65	32.4	...
			85° 10′W.	10	−1.60	32.0	...
			Through thin ice	25	−1.60	32.4	...
				50	−1.05	32.8	...
				100	−1.30	32.8	...
				(NB)			

TABLE I—(concluded)

	1955						
B7	Apr. 11	B33	Admiralty Inlet	0	−1.65	32.2	...
			73° 45′N.	5	−1.70	32.4	...
			84° 40′W.	10	−1.70	32.6	...
			At floe edge	25	−1.70	32.6	...
				50	−1.70	32.6	...
				100	−1.70	32.6	...
				(NB)			
B8	Apr. 26	B34	Navy Board Inlet	0	−1.75	...	...
			73° 45′N.	5	−1.75	...	...
			81° 25′W.	10	−1.75	...	...
			At floe edge	25	−1.75	...	...
				40	−1.75	...	...
				50(B)			
B9	May 6	B35	Eclipse Sound	0	−1.75	...	...
			72° 45′N.	5	−1.75	...	...
			78° 05′W.	10	−1.75	.. '	...
			Through seal hole	25	−1.75	...	...
				50	−1.75	...	...
				100	−1.55	...	...
				(NB)			
B10	May 18	B37	Baffin Bay	0	−1.70	...	...
			72° 52′N.	5	−1.70	...	...
			75° 50′W.	10	−1.75	...	...
			At floe edge	25	−1.60	...	...
				50	−1.75	...	...
				100	−1.50	...	...
				(NB)			
B11	May 31	B37	Baffin Bay	0	−1.20	...	...
			72° 52′N.	5	−1.25	...	...
			75° 50′W.	10	−1.30	...	...
			At floe edge	25	−1.50	...	...
				50	−1.60	...	...
				100	−1.50	...	...
				(NB)			
B12	June 13	B35	Eclipse Sound	0	−1.65	...	...
			72° 45′N.	5	−1.70	...	...
			78° 05′W.	10	−1.70	...	...
			Through seal hole	25	−1.75	...	...
				50	−1.75	...	...
				100	−1.50	...	...
				(NB)			
B13	June 27	B35	Eclipse Sound	0	0.05	<8.8	...
			72° 45′N.	5	−1.20	32.6	...
			78° 05′W.	10	−1.40	32.6	...
			Through tide crack	25	−1.60	32.4	...
				50	−1.65	32.6	...
				100	−1.60	33.0	...
				(NB)			
B14	July 29	B38	Eclipse Sound	0	+1.90	...	...
			72° 43′N.	5	+0.15	...	...
			78° 10′W.	10	−0.15	...	...
			From boat	25	−0.70	...	...
				50	−1.45	...	...
				100	−1.55	...	...
				(NB)			

*(NB) signifies no bottom at 100 m.; (B) indicates bottom at depth shown.

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of the reversing thermometer i.e. ±0.05 degree C. The temperatures in Table I are therefore given to the nearest 0.05 degree C.

The salinities were obtained either by silver nitrate titration, or by hydrometer determination of specific gravity, or by both methods. The titrations were made in the houses of residents in the Arctic settlements and consequently the apparatus used had to be simple so that it would not require much space in operation, could be easily set up and dismantled, and could be carried from settlement to settlement. The volumes of the samples of sea water titrated were 20 ml. and the strength of the silver nitrate solution used was such that approximately 20 ml. neutralized the samples of sea water. The burette was read to an accuracy of 0.05 ml. and from the figures obtained the salinity has been calculated to an accuracy of 0.1‰.

The hydrometer readings of specific gravity were considered accurate to 0.0001, and from the measurements of specific gravity and temperature the salinity has been calculated by means of Knudsen's tables to an accuracy of 0.2‰. During the winter, unless the specific gravity was recorded immediately after the sample was brought to the surface, ice began to form in the Nansen bottle and the beaker. The formation of ice in sea water increases the salinity of the residual liquid and where freezing occurred the salinities obtained were inaccurate and have not been included in the table. Freezing could not be prevented on some occasions (e.g. collection B8, Table I), because the tent in which the readings were made was heated by only one primus stove. While making collections B5, B6 and B7 the tent was heated by two stoves and freezing was delayed sufficiently to permit readings.

In three cases (collections B4, 0 m.; B6, 10 m.; B13, 25 m.) salinities are given which indicate density inversions. These have been included in the table because there is a possibility that density inversions can occur temporarily beneath rapidly forming ice. However, the anomalies in the salinities are so close to the estimated limits of accuracy obtainable under the condition and with the methods described above, that little significance can be attached to the indications of these density inversions. The salinity value for collection B4 at 10 m. has been deleted because it was too high to be considered reliable, the error probably arising from partial freezing of the sample while being carried to the settlement, and subsequent incomplete mixing.

These data for subsurface temperatures and salinities of polar sea water were obtained in order to show some of the fluctuations throughout a full annual cycle in the marine environment which affect the shallow water benthos and plankton. The value of the data lies in the fluctuations they reveal, about which there was no information previously available from the Canadian Arctic.

CORONATION GULF AND VICINITY

The salinities in collection B2 (station B17) indicate that the surface brackish layer described by Tully (1952) extends to a depth greater than 10 m. This layer probably arises each summer from the melting of the winter ice cover and the large number of major rivers that drain into the region (see accompanying

Map of the Canadian Arctic archipelago showing the position of the collecting stations at which temperature and salinity observations were made.
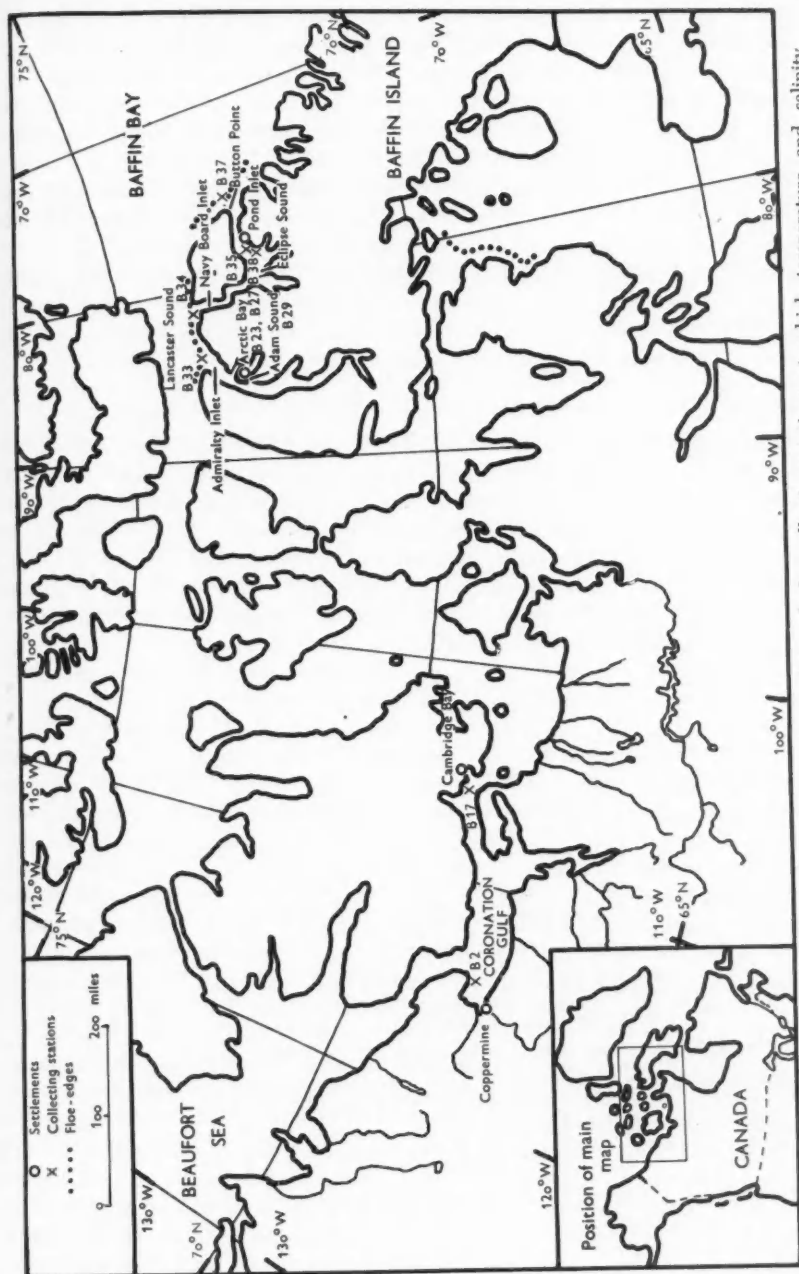
Figure). The low temperatures in the upper layers recorded in May (collection B1, station B2) before the summer thaw had properly begun, compared with the temperature below 50 m. in August (coll. B2, sta. B17) little affected by the seasonal changes, indicate that the water becomes homothermous during the winter. The summer stratification will therefore disappear and the surface brackish water will mix with the deeper saltier water.

The agreement in the salinities at 50 m. and below in both collections B1 and B2 suggests the possibility that such low salinities (less than 30‰) are characteristic of the deep water of the region. These however can only develop and be maintained if there is a restricted horizontal exchange with neighbouring more saline water masses. This is quite possible because the Coronation Gulf region is separated by several hundred miles of fairly narrow channels from the nearest extensive stretches of open sea, the Beaufort Sea and Baffin Bay.

NORTHERN BAFFIN ISLAND REGION

The collections B3 to B14 at stations B23, B27, B29, B33, B34, B35, B37 and B38 are within a region so constant physiographically and so affected in its entirety by the eastward current of polar water flowing through Lancaster Sound (Kiilerich, 1939), that the data from these collections can be considered as a group. In this region the temperatures recorded between 90 and 100 m. vary between —1.30 and —1.75°C., and the salinities at the same depth vary between 32.5 and 33.0‰. These temperatures and salinities represent the variation in the sea water almost uninfluenced by seasonal changes.

Temperatures. On September 22, 1954, (coll. B3, stn. B23) the uniform temperatures down to 10 m. indicated that the surface layers were beginning to cool below the summer maximum. The surface of Arctic Bay froze in October, and by the end of the month (coll. B4, stn. B27) the water down to 5 m. was almost freezing while the increasing winter cold was having an effect down to 25 m. By November (coll. B5, stn. B29) the temperatures had become stabilized down to 25 m. at —1.65°C., which is almost at the freezing point of the sea water as far as can be shown by the limits of accuracy of the hydrometer and thermometer. Sverdrup *et al.* (1946) gave —1.72°C. as the freezing point of sea water with a salinity of 31.6‰. The subsequent slight decrease in the temperature of the upper layers to —1.70 and —1.75°C. corresponded with a slight rise in salinity. In collection B6 (stn. B29) and collection B7 (stn. B33) the salinity was generally between 32.4 and 32.8‰ which indicated a freezing point of —1.77°C.

The drop in temperature of the water at 50 m. depth lagged considerably behind the cooling in the upper layers and the temperature did not stabilize at the winter level until after December.

On May 31, 1955, the water at the floe edge by Button Point (coll. B11, stn. B37) was showing the effect of the rising summer air temperatures. Two weeks later a series of temperatures (coll. B12, stn. B35) taken through a seal's breathing hole in Eclipse Sound revealed that the water there, beneath solid ice, was still unaffected by the summer thaw. By June 27 however (coll. B13, stn. B35) the surface temperature of the under-ice sea water had begun to rise, but this

was almost a month after the same effect had been noted at the floe edge. Not until the ice had broken almost completely at the end of July (coll. B14, stn. B38) did the water in Eclipse Sound begin to warm extensively.

Salinities. During the early part of the winter an increase of the salinity in the upper 50 m. was observed and furthermore the salinity tended to become similar at all levels with a value between 32.4 and 32.8‰.

The reasons for these changes were the increase in the surface salinity due to the formation of ice (see Table II) and the strong cooling of the surface layers.

TABLE II.—Formation of ice in Arctic Bay during the winter 1954–1955.

Date	Approximate thickness of ice	Comments
1954		
Oct. 4	Slush ice	On shore and surface
Oct. 11	Very thin	In patches on surface
Oct. 13	1 inch	Entire surface frozen; ice later broken by wind
Oct. 18	Variable	Still possible to use the boats; patches of ice in Adam Sound strong enough to support sleeping seals
Oct. 19	2 to 3 inches	Entire surface frozen, boats drawn onto shore; during the next week the ice gradually increased in thickness, but patches of open water were occasionally formed by strong winds.
Oct. 26	...	First Eskimo arrived in the settlement by sled over the sea ice.
Oct. 27	6 inches	Benthos collections started through the ice.
Nov. 4	18 inches	
Nov. 9	24 inches	
Nov. 26	36 inches	
Dec. 2	...	Benthos collections through the ice stopped.

This caused an increase of the surface density followed by a strong vertical mixing, which broke down the summer stratification of the water.

The one salinity record obtained during the summer of 1955 (coll. B13, stn. B35) revealed the initial development of a brackish water layer, but unfortunately no further data were obtained.

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